Bulletin
of
The Geological Society of America

VOLUME 68 December 1957 NUMBER 12 PART 1

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Subscription $15.00 per year.
Printing Office: Mt. Royal & Guilford Aves., Baltimore 2, Md.
Communications for publications should be addressed to The Geological Society of America, Dr. H. R. Aldrich, Secretary, 419 West 117 Street, New York, N. Y.
Please give notice of change of address 4 weeks in advance. Claims for nonreceipt of the Bulletin of a given month must be sent to the Secretary of the Society before the end of the second succeeding month.

Entered as second-class matter at the Post Office at Baltimore, Md., under the Act of Congress of July, 16, 1894.
Accepted for mailing at special rate of postage provided for in Section 1103 Act of October 3, 1917, authorized on July 8, 1918.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 68, PP. 1585-1604, 13 FIGS. DECEMBER 1957

HALOGEN-ACID ALTERATION OF ASH AT FUMAROLE NO. 1, VALLEY OF TEN THOUSAND SMOKES, ALASKA

By T. S. Lovering

Abstract

A series of specimens of ash and pumice, collected outward from the throat of Fumarole No. 1 of Zies in the Valley of Ten Thousand Smokes in 1952, has been analyzed for major and minor constituents. The bulk density—approximately 1.00 gm/cc for unaltered ash—was determined by weighing blocks of known volume, and chemical addition or subtraction was calculated for unit volume. Elements readily converted to volatile fluorides or chlorides were leached near the hot throat, but hydrolysis resulted in some late-stage addition in the innermost zone. Condensation of steam and inward movement of hot acid water resulted in outer zones of oxidation and leaching and an intermediate zone of boiling and evaporation, which was especially enriched in alumina and water of hydration.

Appreciable quantities of Pb, Zn, Cu, As, Cl, F, and SO_4 were added to the innermost zone (1 inch), and Ni, Co, B, and Sc were concentrated in the intermediate zone about 2 feet from the throat. No carbonate is present in any zone.

Magnetite, hematite, goethite, hydromica, opal, montmorillonite, and kaolinite are the chief alteration minerals. The alteration is similar to that produced by strong sulfur acids elsewhere, but the gas of Fumarole No. 1 contained only 7 ppm S in 1917, and 70 ppm in 1919. In contrast it carried 240 ppm of HCl, and 30 ppm HF in 1917—the only year in which samples of halogen gases were collected in the valley. The halogen-acid alteration differs from sulfur-acid alteration chiefly in the greater loss of SiO_2 relative to Al_2O_3.

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Introduction

Fumarolic and hot-spring alteration of rocks has been studied in many localities, but in none of these, so far as the writer is aware, have the halogen acids been major constituents of the volcanic emanations, except in the Valley of Ten Thousand Smokes. The study of alteration carried on in this area by the early workers was quite incidental to the major purpose of studying the emanations and the incrustations of the fumaroles, and it was not until recently that suitable specimens became available for study of the chemical changes near a fumarole. In 1952, however, R. E. Wilcox of the U. S. Geological Survey collected a suite of specimens from alteration zones adjacent to Fumarole No. 1 of the Valley of Ten Thousand Smokes, and these specimens were made available to the writer.

X-ray diffractometer studies of the mineralogy, quantitative spectrographic determinations for minor constituents, and chemical analyses for the major constituents and many of the minor constituents were made in laboratories of the U. S. Geological Survey (Tables 1, 2). Although the material had been leached by rains for many years, there is still a small residue of soluble material in some of the specimens, and attempts to gain powder densities gave inconsistent results. Bulk densities were determined by weighing a carefully measured volume of ash and computing the grams per cubic centimeter.

Previous Work

The Valley of Ten Thousand Smokes was discovered in 1916 by a botanist, Robert F. Griggs (1922), and the first studies of the chemical, thermal, and geological aspects of this intensely interesting area were made in 1917.

The explosive eruption of Katmai (?) volcano in the Aleutian chain on June 6 and subsequent days of 1922 blanketed the area with a heavy ash fall and expelled a large volume of acid gases that led to acid rains and fumes rich in sulfur acids, the effects of which were unpleasantly perceptible for more than 1000 miles from the volcano. So far as known, all observers agree that the ash on the floor of the Valley of Ten Thousand Smokes must have been emplaced as an incandescent flow of gas-saturated ash very early in the first volcanic episode. The presence on top of the ash flow of several layers of ash that were correlated with the ash falls of Katmai for the days following June 6, proved to the satisfaction of the Griggs expeditions that the ash flow ("sand flow" of Fenner) was emplaced at the earliest stage of the eruption, and that explosions in Katmai followed it (Griggs, 1922; Fenner, 1923). Recent work by Howel Williams, Garniss Curtis, and the late Werner Juhle (Williams, 1954; Curtis, 1955) led them to conclude that Novarupta at the head of the Valley of Ten Thousand Smokes was the chief center of volcanic activity, rather than Katmai, and that the flow of incandescent ash followed the first explosive phase of a pyroxene-free pumice, but was earlier than some of the late pyroxene-bearing pumice. Assuming this interpretation to be correct, the contrast between the gases accompanying the ash flow and those of the first explosion can be explained as gas phases appropriate to the initial explosion and a subsequent nuée ardente. As pointed out by Krauskopf (1948), the insoluble gases which predominate at an active ash vent of a volcano are rich in sulfur, whereas the soluble gases that are retained in the quiet lava stream, escaping later in minor fumaroles, are very low in sulfur and high in halogens. The earliest Katmai (?) explosion, which was rich in sulfur acids, probably represented the culmination of increasing vapor pressure of the less soluble volatiles, and was then followed by the extrusion of a lava saturated with the more soluble halogen acids at depth. Such a lava escaping through the conduit opened by the earlier explosion would assuredly vesiculate greatly and yield an incandescent froth such as the nuée ardente that poured into the Valley of Ten Thousand Smokes, where its contact with surface water would immediately engender fumaroles.

The fumaroles as observed in 1916–1919 were in large part steam, but the lack of seasonal variation in the temperature of the fumaroles led Griggs (1922, p. 246) to conclude that some of the steam was magmatic, but he believed, as did his colleagues, that the major part was contributed by ground water soaking into the hot porous ash.

After 1919 the activity of the fumaroles waned rapidly throughout most of the valley, but a few "smokes" persisted near the head of the valley (closer to the center of volcanic activity) and were still visible in 1952.

There has been much debate as to the origin of the fumaroles, but the early workers in the valley, including Fenner, Zies, Allen, and Griggs (Fenner, 1923; Griggs, 1922) believed that the activity was largely caused by exhalations from

a cooling and crystallizing sill or other injection below the valley. Recently this view has been challenged, and Howel Williams (1954) has suggested that the fumaroles represent the original gas accompanying the ash flow plus the vaporized ground water that soaked into the flow after it came to rest. The rapid diminution of activity throughout most of the valley after 1920 favors the view that most of the fumaroles were of local origin, but the persistence of a few fumaroles near the head of the valley through a period of 40 years indicates that some gas came from a deep-seated source.

The volume relations of the gas in 1919 as determined by Allen and Zies (Zies, 1929) shed some light on this problem. According to Fenner the total volume of ash in the valley was more than 1 cubic mile, or approximately 5 cubic km. In 1919 the total volume of gas, including water vapor, being expelled annually is calculated as approximately 800 km³ per year (at 100°C. and at atmospheric pressure) and would have a mass of about 500,000,000 metric tons. The ratio of voids to solid matter in the ash is about 1.5:1, or about 60 per cent of the total volume, and there is no evidence of great compaction since emplacement; it therefore seems unlikely that the initial volume of gas imprisoned in the ash flow after the first violent outburst could have been much more than twice the total volume of the ash that was found in 1919, or approximately 10 km³; if the initial temperature was about 850°C., this would be equivalent to only a little more than 3 km³ at 100°C. at 1 atmosphere pressure. The total volume and mass of the acid gases given off annually as calculated from the volume of gas measured in 1919 (Zies, 1929, p. 4), and the composition of the gases collected in 1917 (Allen and Zies, 1923, p. 126) were approximately:

CO_2	0.80 km³
HCl	0.96 km³
HF	0.26 km³
H_2S	0.24 km³
Total	2.26 km³

According to Zies (Personal communication) the error in calculating the total volume of gas in the Valley of Ten Thousand Smokes was probably less than 50 per cent (*e.g.*, it could not have been less than half of the amount calculated nor more than twice the amount). The total volume of sulfur and halogen gases given off annually as calculated from samples taken in 1917, 5 years after the fumaroles started, approximates half of the probable total initial gas content of the ash flow; it would seem therefore that some source of acid gas was tapped in addition to that originally imprisoned in the ignimbrite when the ash flow came to rest.

Character of Fumarolic Emanations

The chemical composition of the fumaroles varied from place to place, and probably with time, but the average composition, according to Allen and Zies (1923, p. 126, 142) was approximately 0.12 per cent HCl, 0.03 per cent HF, 0.03 per cent H_2S, 0.10 per cent CO_2, 0.002 per cent O_2, 0.015 per cent CH_4, 0.041 per cent N_2 + A, and about 99.7 per cent steam. It should be noted, however, that this is the average analysis of the water-soluble gases of 25 samples collected by Shipley in 1917 and analyzed by Allen and Zies in 1921, plus the average of the "fixed gases"—*e.g.*, CO_2, O_2, CH_4, N_2, and A—collected from many other fumaroles and analyzed on the spot in 1919. H_2 was determined and calculated as H_2S because the H_2S present was decomposed by copper tubing in the collection train. The value of the H_2S calculated from H_2 for the "fixed gas" (0.024) agrees well with that calculated from total sulfur found in the "water-soluble gas" (0.029). Unfortunately, the location of the fumaroles that correspond with Shipley's sample numbers are different from the numbers shown on the map accompanying the reports of Allen, Zies, and Fenner, so that the location of the gases sampled is almost impossible to ascertain.

Allen and Zies (1923, p. 145, 146) found no correlation between temperature of fumaroles and the character of the fixed gases (CO_2, O_2, CH_4, H_2, H_2S, N_2, and A) but saw some evidence of a correlation between temperature and the composition of the soluble gases HCl, HF and H_2S (the latter representing all sulfur present, composition of compounds unknown, but calculated as H_2S). When the temperatures of the fumaroles determined crudely by Shipley, as given by Allen and Zies (1923, p. 148) are plotted against the composition of gases, there is a pronounced trend toward decreasing quantities of HCl and HF in the gases with lowering temperature, and there is also a notable increase in the proportion of "H_2S" present. In the fumaroles with lower gas content

and in the analyses of fumaroles having a temperature of approximately 100°C. the proportion H_2S:HF:HCl (in volume per cent) is approximately 10:7:17; those at a temperature of about 250°C. have a 10:10:40 ratio, those at a temperature of 300°C. are 10:20:80, and those at a temperature of 350°C. are 10:24:70, and in the two having a temperature of more than 400°C., one (Fumarole no. 1 of Allen and Zies) shows a ratio of 10:40:340, and the other a ratio of 10:2.7:3.7. It is probable, however, that the sulfur which is all calculated as H_2S, was present chiefly as a sulfur oxide in the high-temperature fumaroles. Except for the last analysis, the proportion of halogen acids to hydrogen sulfide or sulfur acids is high whether considered in molar per cent or volume per cent.

As shown in Figure 1, the relation of the sulfur and halogen acids in the gases also shows a marked geographic control. The observation made by Shipley in 1917 that the north or lower end of the valley was deficient in hydrogen sulfide and had an abundance of hydrochloric and hydrofluoric acid, is borne out by the analyses for H_2S made by Allen and Zies in 1919; the three fumaroles analyzed near the end of the ash flow in the northern part of the valley contained 0.002 to 0.010 per cent of H_2S, whereas all those to the south were much higher, ranging from 0.019 just south of the low sulfur area to 0.051 per cent on the north slope of Baked Mountain. The rapid fall in temperature of Fumarole No. 1, the northernmost of the fumaroles, and the parallel decline in activity of others near by, suggests a displacement of gas originally trapped in the ash flow when it was emplaced in 1912. These are the halogen-rich fumaroles low in sulfur that were concentrated near the northern end of the incandescent ash flow. The area richest in the sulfur-acid gases, on the other hand, surround Baked Mountain and Broken Mountain near Novarupta at the south end of the Valley of Ten Thousand Smokes where activity persisted the longest. According to R. E. Wilcox (Personal communication) there was still minor fumarolic activity in this region in 1952. Mueller, Juhle, and Coulter (1954, p. 63, 66) also noted many small fumaroles on an arcuate system of fissures around Novarupta that year, and as noted earlier, their restudy of the geology led them to conclude that this area—not Katmai—was the main center of the 1912 eruption.

It is difficult to imagine chemical reactions that would rob a gas of sulfur while passing through siliceous ash, and yet permit hydrochloric and hydrofluoric acid to come through in essentially the same amounts as found in the original fumaroles near Novarupta and Baked Mountain, which contain a high proportion of sulfur acids. If the source of the gas in the northern and southern parts of the ash flow was different in 1919, however, this difficulty does not exist; the writer has reached the conclusion that, in contrast to the Baked Mountain-Novarupta fumaroles, the gases of Fumarole No. 1 represent a sample of the original gas accompanying the emplacement of the hot ash flow plus vaporized surface water that was volatilized by the heat remaining in the material after it came to rest.

The area between Baked Mountain and Novarupta is characterized by relatively high CO_2, as well as sulfur, and the fumaroles in the north end of the flow are also low in this gas.

A relatively high concentration of sulfur gases is characteristic of vent gases during an eruption, and sulfur and carbon dioxide, which commonly persist in the vent gases as long as any fumarolic activity is evident, sometimes continue through the decades between eruptions. It seems reasonable to explain the geographic differences in composition of gases as caused by the increasing contribution of sulfur and carbon dioxide from persistent vent gases spreading out into the ash flow from the eruptive center. Similarly, the increasing proportion of sulfur to halogens with decreasing temperature would relate to the more nearly constant but small contribution of the deep-seated source while the abundant halogen-rich gases accompanying the hot ash flow diminished in amount as the temperature of the fumarole fell and the energy of the local fumarolic system declined. Streams and other surface water entering the ash near the head of the valley would quickly become saturated with fumarolic gases, and then would release them again downstream as they became heated and lost volume through evaporation. Much of the CO_2 and H_2S in the central and northern fumaroles may have had this origin.

Fumarole No. 1 of Allen and Zies

Temperature and Character of Gas

The area near Fumarole No. 1 had a substantial amount of attention by the early expeditions, and it is possible to infer with confidence the general nature of the emanations and the thermal history of this locality. Ac-

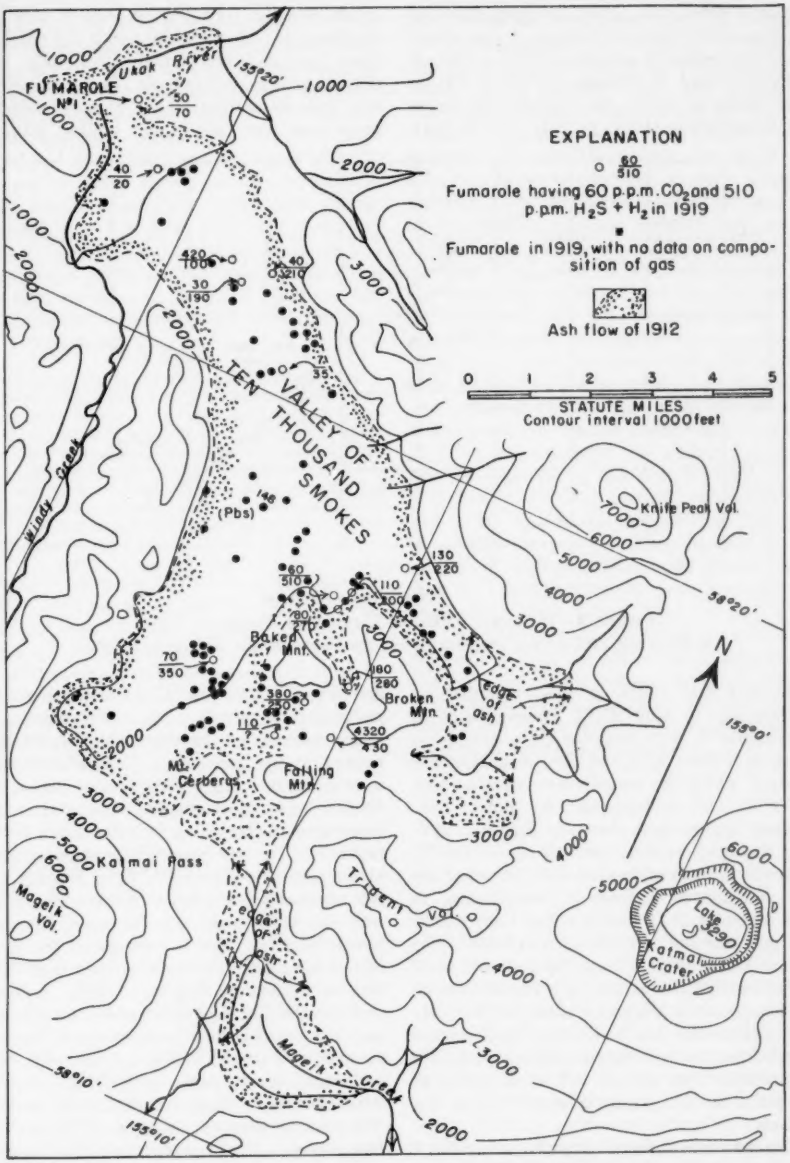

FIGURE 1.—MAP OF VALLEY OF TEN THOUSAND SMOKES

Shows location of fumaroles in 1919, and the CO_2 and H_2S in ppm in the gas phase, where known. Map from published data by R. F. Griggs, C. F. Maynard, E. T. Allen, and E. G. Zies.

cording to Zies (1929, p. 34), the temperature of the emanations of Fumarole no. 1 was above the boiling point of mercury (357°C.) when it was visited by J. W. Shipley in 1917. In 1918 a temperature of 220°C. was recorded by Sayre and Hagelbarger (1919, p. 262), but in 1919 on the samples collected by Shipley were not correlated by Allen and Zies with the numbers given the fumaroles in their 1919 study, it is possible to identify Fumarole No. 1 as one of the two fumaroles from which Shipley collected gases that were above the boiling point of

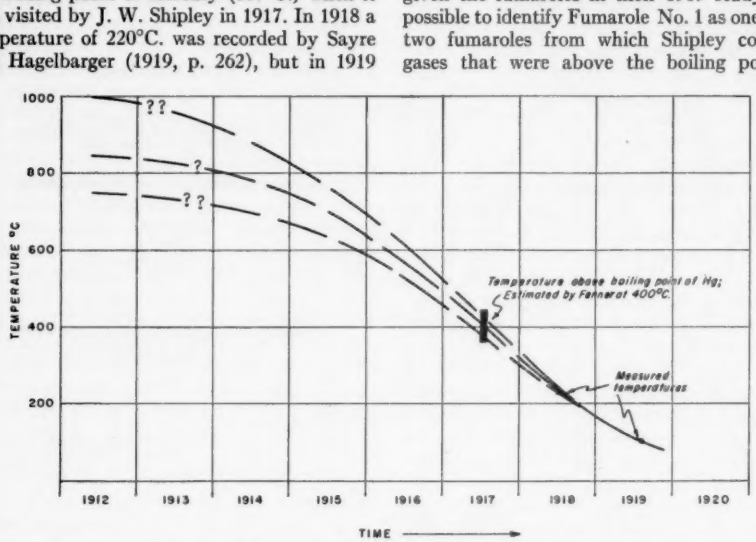

FIGURE 2.—PROBABLE THERMAL HISTORY OF FUMAROLE NO. 1
Of Allen and Zies. At the northern end of the Valley of Ten Thousand Smokes.

Allen and Zies (1923, p. 104) recorded its temperature as only 97°C. Temperatures as high as 645°C. were recorded elsewhere in the valley in 1919 by Allen and Zies. Magnetite was common where the temperatures were as high as 500°C. This evidence and the plot of temperature against time shown in Figure 2, indicate the temperature was well above 600°C. earlier in the 5-year period that preceded the first attempt to measure its temperature in 1917 and suggests that the initial temperature was probably between 800°C. and 900°C. The vent of Fumarole No. 1 was dry and cold when visited in 1952, but presumably it went through an evanescent hot springs stage in the early 20's, before the ash bed cooled and ground water ceased to vaporize in sufficient quantity to maintain the porous tuff in a saturated condition as the steam condensed near the surface.

The character of the gas from Fumarole No. 1 is not specifically given, except for fixed gases (Allen and Zies, 1923, p. 126). Determination of the soluble gases, namely HF, HCl, and total sulfur calculated as H_2S was made on samples collected by Shipley in 1917 and analyzed by Allen and Zies in 1921. Although the numbers

mercury (Zies, 1929, p. 34). Identification of the particular gas sample is made with some confidence because of the statement in Shipley's paper that "hydrochloric and hydrofluoric acids were common constituents of the vapor, the former being most markedly present in the lower part of the valley 10 miles below Novarupta." Of the two fumarolic samples collected at temperatures above 400°C. by Shipley, one was unusually low in hydrochloric acid and one was unusually high. As Fumarole No. 1 is about 10 miles from Novarupta at the lower end of the valley, there seems little doubt that this corresponds to Shipley's sample no. 3 and to Fumarole No. 1 of Allen and Zies. The volume per cent of the soluble gases of Shipley's sample no. 3 are: HCl 0.024 per cent, HF 0.003 per cent, sulfur acids (calculated as H_2S) 0.0007 per cent (Allen and Zies, 1923, p. 142). The calculations are for a gas at 100°C. and 760 mm pressure. The fixed gases from this fumarole as determined in 1919 are: water 99.97 per cent, CO_2 0.005 per cent, O_2 0.001 per cent, H_2S + H_2 0.007 per cent, N_2 + A 0.017 per cent (Allen and Zies, 1923, p. 126). The method of collection and storage of the gas samples collected by Shipley are such as to make the amount of

sulfur determined in the samples subject to some error, and there is no assurance that this sulfur represented hydrogen sulfide rather than SO_2 or SO_3; the abundance of oxidized iron and gypsum in the fumarolic incrustations indicates sulfur was in the oxidized form. The presence of minor hydrogen sulfide in 1919 was well established in the field, and the figure of 0.007 per cent for $H_2S + H_2$ is believed to be reliable.

No specific description of the area around Fumarole No. 1 is given by Shipley who examined it in 1917, but according to Sayre and Hagelbarger (1920, p. 262), this fumarole was the first conspicuous fumarole seen on approaching the valley from the northern extremity of the ash flow.

> "The hole was about 18 inches in diameter on a fissure perhaps 100 feet long running east and west. The surface of the fissure was light colored while the throat had a hard brown incrustation. The gases were emitted under considerable pressure and were not condensed until several feet from the vent. The region was visited July 13th and again on August 1st. No change could be observed; 220°C was registered both at the surface and five feet down in the throat. Photograph 3769."

In 1919 when the temperature had fallen to 97°C. the fumarole, as described by Allen and Zies, had incrustations containing a substantial amount of magnetite and ferric oxide in the throat intermixed with white crusts of opal. In the vent where steam was condensing freely, the incrustations were similar to those found at other vents near by in cooler areas and consisted chiefly of opal, gypsum, sulfur, a little arsenic sulfide, and barium sulfate. The material from the throat (which would correspond to Zone 1 in the alteration series discussed in this paper) contained 0.019 per cent Sn, 0.054 per cent Pb, and 0.034 per cent Zn. Spectrographic examination of the tin group precipitate showed traces of arsenic and antimony, of the lead group a minor amount of copper and silver, and of the zinc group a small but definite amount of cadmium. Allen and Zies establish the fact that most of the lead (at least 70 per cent) was present as lead sulfate, and that most of the zinc was present as a soluble salt. The presence of lead in the form of sulfate in this fumarole is noteworthy as Fumarole No. 148, 7 miles south (Fig. 1), contained copper sulfide, sphalerite, and galena even after the steam temperature fell to 97°C. as it had in 1923. No. 148 contained abundant hydrogen sulfide in the steam, however, and stood in sharp contrast to Fumarole No. 1 in which the steam issuing in 1919 gave only a feeble reaction for hydrogen sulfide.

Allen and Zies found that many of the incrustations that contained opal-like material had pasty substances from which both ammonium and sodium alums could be extracted with water. They conclude that the aluminum compounds, which are hydrolized at elevated temperatures, must have been derived from pumice at or near the surface and could not have been transported in the gas phase. Shipley, however, found corundum in some incrustations in the hotter vents and believes that it was formed by a gas-phase reaction. Most of the leaching and secondary concentration of alumina, however, must have been carried on by condensed hot acid waters, which presumably dropped their load in a zone where the temperature of the solutions reached the boiling point. Allen and Zies note that the preponderance of lead over zinc in the incrustations of Fumarole No. 1 is the reverse of the content of these two metals in the unaltered pumice; this they ascribe to the fact that zinc compounds are relatively soluble, whereas both lead sulfate and sulfide are not. The difference in solubility would insure an increase in the amount of lead and a decrease in the amount of zinc, even though more zinc were present in the emanations (Zies, 1929, p. 36).

It is highly probable that many of the metals were not fixed in the altered rocks adjacent to the fumarole simply because of the dearth of hydrogen sulfide in the emanation throughout the history of the fumarole, in contrast to the fumaroles farther to the south.

Alteration

In 1952, according to Wilcox, the site of Fumarole No. 1 was a dry, dead orifice with several alteration zones surrounding it. The throat was lined with a hard, bluish-gray crust of altered ash (zone 1), and was in sharp contrast with a light-pinkish-gray zone of soft altered ash about 18 inches thick (zone 2). This gave way abruptly to a hard green vertical layer about 2 inches thick (zone 3) that graded into an irregular hard purple layer not more than 1 inch thick (zone 4). The next zone outward was a soft white layer about 2 feet thick (zone 5) which showed a moderately sharp contact with a zone of soft brown altered ash more than 10 feet thick (zone 6), which graded outward into unaltered gray ash (zone 7) through a transition zone several feet thick. Samples for analysis were taken about 10 inches below the surface from a trench dug across the zones.

The zoning around the fumarole throat must be regarded as the result of a combination of processes: first, the presence of a gas phase containing abundant halogens whose temperature was at first very high but gradually fell through a period of 7 years to the temperature and then slowly worked its way toward the orifice.

Movement of water in the tuff near a vent would be profoundly influenced by the temperature and velocity of the gases in a vent; the quantity of water moving toward a fumarole

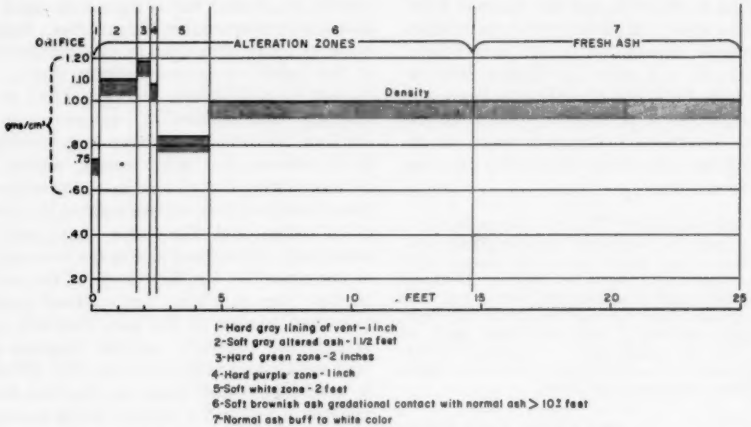

FIGURE 3.—ALTERATION ZONES ADJACENT TO FUMAROLE NO. 1

Those sampled in 1952 by R. E. Wilcox are indicated in the upper part of the figure; the bulk density of the material in the alteration zones is shown in the graph below.

of boiling water; second, the condensation and leaching action of acid gases in liquid water near the surface, and the movement of this material toward the hot fumarole throat which undoubtedly acted as an aspirator by vaporizing and drawing in water from the surrounding cooler area. The dominance of leaching or precipitation is reflected by a decrease or increase in bulk density, as shown in Figure 3.

If the rate of temperature fall between 1917 and 1919 is projected backward, the plot suggests that the temperature of Fumarole No. 1 was above 800°C. in 1912 (Fig. 2). Although the temperature of the ash flow at the time of eruption is not known, it is unlikely that it was above 1000°C., and it may have been as low as 800°C.; the known points on the plot suggest that for several years the gas issuing from Fumarole No. 1 was at a high temperature, but that the temperature fell at a fairly rapid rate to the temperature of boiling water during the last few years of its activities. If this picture of the thermal history is correct, it is reasonable that the zone of condensation of water remained at a fairly definite distance away from the throat of the fumarole for the first few years would be greatest when the aspirator effect of gases moving at high velocity was greatest, and this in turn would be at a maximum at high temperature when the volume of gas would be largest. If the temperature of the throat were kept constant and the inward movement of the cooling ground water slowed, then the zone of boiling would spread outward. Conversely, this zone could move inward if the temperature of the throat fell and the movement of water remained constant. The diminution of both temperature and volume of gas during the life of a fumarole probably sets up these conflicting tendencies, and the zone of boiling may be relatively static for a substantial part of the life of a fumarole. This zone would move out to an equilibrium distance shortly after the birth of the fumarole and must retreat as the hot springs stage is approached, but for a long time its movement could be exceedingly sluggish.

There seems little doubt that the changes within the first and second zones of Fumarole No. 1 were largely induced by gas-phase reactions and that those in zones 5 and 6 were largely in response to the action of liquid

solution, essentially at the temperature of boiling water. Most of the soluble products formed during the activity of the fumaroles have been removed by melt water from snow and the heavy rainfall in the three decades since the fumarolic activity died out, but some samples still contain a minor amount of soluble material. Zones 3 and 4 probably represent a zone of boiling between the area that was dominantly permeated by the hot-gas phase and that on the outside which was subjected chiefly to the action of liquid solutions.

Where rocks are altered with an attendant loss or gain of porosity, figures giving only weight per cent are misleading; comparison of losses or gains per unit volume, on the other hand, are very revealing. Bulk density can be used to convert weight per cent to weight per unit volume, and in Tables 1–4, both weight per cent and weight per unit volume (mg/cm³) are given for each analysis.

As shown in Tables 1 and 2, and Figures 4–9, the most noteworthy changes in the major constituents in zone 1 is the loss of silica, iron, and titanium, and among the minor constituents a gain in water, sulfate-sulfur, chlorine, fluorine, lead, zinc, copper, and arsenic.

As shown in Figure 4, the loss of SiO_2 in zone 1 is in contrast to the increase in silica in zone 2, and probably reflects the attack of hydrofluoric acid on silicates below the surface and hydrolysis of the silicon fluoride in the cooler zone next to the throat of the fumarole at the surface. The leaching of silica by aqueous acid solutions in zone 5 undoubtedly continued at times into zones 4 and 3, but deposition of silica is evident

TABLE 1.—CHEMICAL ANALYSIS (WEIGHT PER CENT) OF WALL ROCKS, FUMAROLE NO. 1, VALLEY OF TEN THOUSAND SMOKES

Not detected at spectrographic limits shown in parentheses: Be(0.0001); Ag(0.00005); Au (0.003); Pt (0.003); La (0.005); W (0.01); Ge (0.0005); Sn (0.001); As (0.05); Sb (0.01); Mo (0.001); Cd (0.005); Tl (0.01); In (0.001); Nb (0.001); Ta (0.05); Th (0.05); U (0.05).

Sp. Gr. (Bulk) 0.75 1.10 1.18 1.09 0.84 1.0**** 1.0****

L. M. Kehl, analyst, except as noted otherwise. U. S. Geological Survey.

Field no.	1TL53	2TL53	3TL53	4TL53	5TL53	6TL53	7TL53
Major constituents							
SiO_2	59.08	70.70	55.79	54.41	73.02	72.21	72.67
Al_2O_3	24.82	11.91	25.86	26.86	11.77	12.53	12.86
Fe_2O_3	1.82	4.59	3.11	3.20	1.15	1.99	1.33
FeO	.58	.74	1.41	.99	.59	.90	1.38
MgO	.89	1.36	.76	1.01	.82	.57	.82
CaO	1.47	1.12	1.41	1.15	.98	1.50	1.98
Na_2O	2.47	2.53	1.84	1.70	2.28	3.12	4.01
K_2O	2.41	2.54	1.82	2.02	2.67	2.65	2.64
H_2O-	1.01	.44	1.70	1.17	.33	.27	0.08
H_2O+	4.89	3.52	5.54	6.68	4.18	3.51	1.50
TiO_2	.16	.19	.15	.16	.22	.24	.30
CO_2	.00	.00	.00	.00	.00	.00	.00
P_2O_5	.16	.04	.19	.04	.03	.09	.04
SO_3***	.44	.03	.05	.04	.12	.05	.01
Cl	.12	.21	.15	.16	.19	.14	.15
F-	.14	.06	.12	.21	.08	.08	.05
MnO	.09	.05	.06	.05	.04	.06	.07
Minor constituents							
Pb*	0.0350	0.0010	0.0005	0.0002	0.0008	0.0010	0.0010
Pb**	.05	<.001	<.001	<.001	<.001	<.001	<.001
Zn*	.0310	.0048	.0040	.0028	.0035	.0046	.0053
Zn**	.03	<.02	<.02	<.02	<.02	<.02	<.02
Cu*	.0048	.0015	.0008	.0017	.0012	.0018	.0021
Cu**	.003	.001	.0009	.0005	.0005	.001	\.001
Sb*	.0003	.0003	.0002	.0001	.0002	.0001	.0001
Y**	.006	.008	.007	.007	.008	.007	.008
B*	.01	.005	.02	.02	.004	.003	.003
As*	.0080	.0005	.0005	.0005	.0005	.0010	.0010
Co**	.0005	.001	.001	.002	0	.0004	.0006
Bi**	.0004	.0002	.0004	.0002	0	0	0
Sc**	.0005	.0004	.0005	.0007	.0003	.0004	.0005
Cr**	.001	.001	.002	.003	.0006	.001	.001
V**	.007	.005	.020	.007	.002	.006	.005
Ga**	.0006	.001	.0005	.002	.0006	.0009	.0008
Be **	.1	.09	.08	.08	.1	.1	.09
Sr**	.07	.03	.04	.04	.03	.05	.05
Bi**	.008	0	0	0	0	0	0
Yb**	.0005	.0006	.0005	.0006	.0006	.0006	.0006
Zr**	.01	.01	.01	.01	.02	.02	.02

* Trace chemical analyses, H. E. Crowe, analyst, U. S. Geological Survey.

** Quantitative spectrographic determination, P. R. Barnett, analyst, U. S. Geological Survey.

*** Calculated from total sulfur. It was assumed that all sulfur was present as sulfate. Sample 2TL53 may contain a little pyrite.

**** Insufficient material for satisfactory bulk density; good determination on fresh ash nearby is 0.98.

TABLE 2.—CHEMICAL ANALYSES (MG PER CM³) OF WALL ROCKS, FUMAROLE NO. 1*

Field no.	174.53	284.53	344.53	474.53	784.53	684.53	774.53
Major constituents							
SiO_2	443.1	777.7	698.3	593.7	630.2	722.1	726.7
Al_2O_3	186.1	131.8	305.1	293.0	98.8	129.3	128.5
Fe_2O_3	9.1	50.5	36.7	34.9	9.7	19.9	13.5
FeO	4.3	8.1	16.6	10.8	5.0	9.0	13.8
MgO	6.7	15.0	9.0	11.0	1.8	5.7	8.2
CaO	11.0	12.3	16.6	12.3	8.2	15.0	19.8
Na_2O	18.5	29.6	21.7	18.5	19.2	31.2	40.1
K_2O	18.1	27.9	21.5	22.0	22.4	26.5	26.4
H_2O-	7.6	4.8	30.0	12.8	2.8	2.7	.8
H_2O+	36.7	38.7	65.4	72.8	35.1	35.1	15.1
TiO_2	1.20	2.1	1.8	1.7	1.8	2.4	3.0
CO_2		.0		-	-	.0	.0
P_2O_5	1.80	.4	2.2	.4	.3	.9	.4
SO_3	3.30	.3	.6	.4	1.0	.5	.1
Cl	1.6	2.3	1.8	1.7	1.6	1.4	1.5
F-	1.0	0.6	1.4	2.3	.7	.8	.5
MnO	.7	0.5	.7	.5	.3	.6	.7
Fe^{3+}	6.4	35.3	25.7	24.4	6.8	13.9	9.3
Fe^{2+}	3.3	6.3	12.9	8.4	3.9	7.0	10.7
Fe	9.7	41.6	38.6	32.8	10.7	20.9	20.7
Minor constituents							
Pb	.300±	.011	.006	.002	.007	.010	.010
Zn	.230±	.053	.047	.030	.030	.046	.053
Cu	.035	.015-	.012	.013	.008	.014	.015
Sb	.000+	.003+	.008+	.001+	.002	.001	.001
Y	.045	.09-	.008+	.08-	.07-	.07	.08
B	.075	.062	.241	.228	.03+	.03	.03
As	.015	.005+	.006-	.005+	.004+	.010	.010
Co	.004-	.011	.012-	.022	<.001	.004	.006
Ni	.003	.002+	.005-	.022	<.001	<.001	<.001
Se	.004+	.004+	.006	.008+	.003-	.004	.005
Weight per cc, in mg	750	1,100	1,180	1,090	840	1,000	1,000

* The figures in Table 2 are obtained by multiplying the weight per cent values given in Table 1 by the appropriate bulk density value × 1000 (to give mg/cm³).

TABLE 3.—CHEMICAL ANALYSES OF TRACHYTE AND ITS ALTERED FACIES, SOLFATARA, ITALY (Rittmann, 1934)

Sp. gr. powder 2.658 2.581 2.428 2.131
Sp. gr. lump 2.460 2.465 2.078 1.230
1 = Fresh alkali trachyte
2 = Weakly altered alkali trachyte 30 cm from fumarole
3 = Strongly altered alkali trachyte at 12 cm
4 = Completely altered alkali trachyte next to fissure

	Weight percent				mg per cm³			
	1	2	3	4	1	2	3	4
SiO_2	58.48	57.82	64.78	81.96	1438.	1427.	1341.	1002.
Al_2O_3	18.71	20.16	14.84	4.00	460.	497.	307.	049.
Fe_2O_3	1.88	2.20	2.54	.72	046.	054.	053.	009.
FeO	2.25	.28	--	--	055.	007.	000.	000.
MgO	1.32	.28	tr	--	032.	007.	tr	000.
CaO	4.18	2.92	0.98	.04	103.	072.	020.	001.
Na_2O	3.45	3.05	4.91	1.46	085.	075.	102.	018.
K_2O	8.05	8.48	8.05	2.34	198.	209.	167.	029.
H_2O-	.17	1.96	.94	1.70	004.	048.	020.	021.
H_2O+	.51	.47	.68	2.05	012.	012.	014.	025.
TiO_2	.80	.68	.50	.65	020.	017.	010.	008.
P_2O_5	.09	.07	tr	tr	002.	002.	tr	tr
MnO	.14	.06	tr	n.d.	003.	002.	tr	n.d.
Cl_2	.16	.10	tr	n.d.	004.	002.	tr	n.d.
SO_3	n.d.	.49	.20	n.d.	n.d.	012.	004.	n.d.
S	n.d.	1.26	1.94	.20	n.d.	031.	040.	002.
	Soluble salts							
Al_2O_3	n.d.	.02	n.d.	.05				
Fe_2O_3	n.d.	.0	n.d.	.12				
CaO	n.d.	n.d.	n.d.	.08				
Na_2O	n.d.	.02	n.d.	.97				
K_2O	n.d.	.04	n.d.	.08				
Cl	n.d.	.02	n.d.	.06				
SO_4	n.d.	.08	n.d.	1.40				
H_2O-	n.d.	.16	n.d.	2.71				
O/Cl	.03	.02	n.d.	.09				
Total	100.16	100.61	100.36	100.50				

Fumarole gas weight percent	
H_2O	91.03
CO_2	8.897±
H_2S	.0422
H_2	.0061
CH_4	.0008
N_2	.0233
Ne+Ar	.0002

SO_2, HCl, O_2, CO: Trace
Temperature 147°C

in them and probably was due to the boiling of acid, silica-laden solutions moving inward from zones 5 and 4.

The behavior of alumina (Fig. 4) is appreciably different from that of silica: the aqueous solutions that dissolved alumina in zone 5 redeposited this material in zones 3 and 4 by evaporation and reaction—kaolinite, mont-

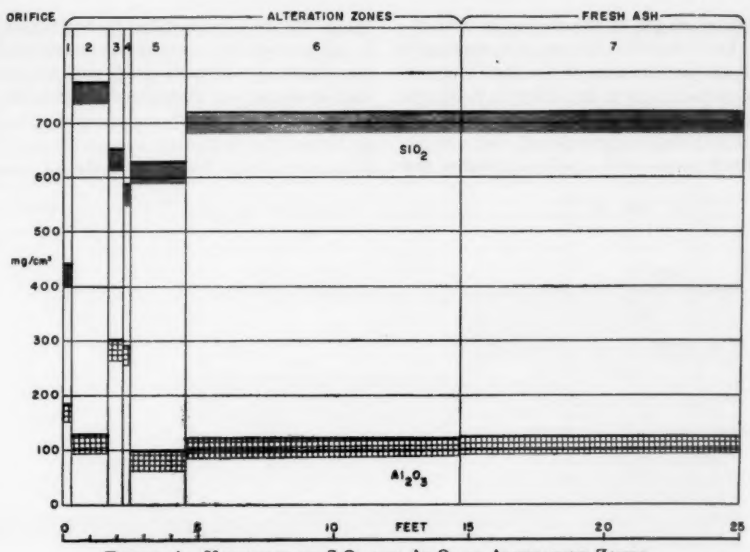

FIGURE 4.—VARIATION OF SiO_2 AND Al_2O_3 IN ALTERATION ZONES
Described in Figure 3. (in mg/cm³)

TABLE 4.—ACID ALTERATION, BUMPASS HELL HOT SPRINGS, LASSEN PEAK, CALIFORNIA

1. Fresh core dacite block, Spring 14, Bumpass Hell, Lassen Peak (Anderson, 1935, p. 244).
2. Bleached transition zone altered dacite block of No. 1 and 3 (Anderson, 1935, p. 244).
3. White powdery exterior altered dacite block of No. 1 and 2 (Anderson, 1935, p. 244).
4. Acid water 95° C., 1922, Spring 14, water boiling violently (Day and Allen, 1925, p. 112).
5. Gas from Spring 14 (Day and Allen, 1925, p. 133).

	Weight percent			mg per cm³			mg per liter		Volume percent	
	1	2	3	1	2	3	4		5	
SiO_2	63.80	75.70	92.20	1461.02	1241.48	1375.78*	SiO_2	236	CO_2	93.70
Al_2O_3	17.55	8.53	1.02	401.90	139.89	015.20*	Al^{+++}	28	CO	none
Fe_2O_3	1.28	1.85	nil	029.31	030.34	nil	Fe^{+++}	5	CH_4	.15
FeO	2.44	1.40	.40	055.88	022.96	005.96	Fe^{++}	17.5	H_2	1.05
MgO	2.02	.05	nil	046.26	000.82	nil	Mg	4.5	H_2S	.40
CaO	2.60	.50	.35	059.54	008.20	005.22	Ca	7	N_2	4.60
Na_2O	2.70	.12	tr	061.83	001.97	tr	Na	29	O_2	.10
K_2O	1.82	.89	tr	041.68	014.60	tr	K	13		
H_2O-	1.85	2.40	2.80	042.37	039.36	041.72	NH_4	15	Total	100.00
H_2O+	2.80	3.42	1.65	064.12	056.09	024.59	Cl	2		
TiO_2	.55	.65	1.25	012.60	010.66	018.63	B_2O_3	4		
CO_2	nil	nil	nil	nil	nil	nil	CO_2			
P_2O_5	tr	tr	nil	tr	tr	nil	H	7		
SO_3	.48	4.58	.35	010.99	075.11	005.22	SO_4	681		
S		.05	.03	-	000.82	.45				
MnO	tr	nil	nil	tr	nil	nil				
Total	99.89	100.14	100.05							
Bulk density*	2.29	1.64	1.49							

* Bulk densities determined by M. V. Denny, Dept. of Mineralogy, University of Michigan, 1947.

morillonite, and hydromica were all found here, but the alumina in zone 2 is essentially the same as that contained in the fresh pumice of zone 7. Aluminum is not easily volatilized and is readily hydrolyzed by water, and it seems probable that in zone 2 where gas-phase reactions were dominant, relatively little alumina was either dissolved or precipitated; in zone 1 some aluminum probably was added by hydrolysis of volatile aluminum fluoride in the early high

temperature stages of the fumarolic activity. Shipley has noted the presence of corundum in the incrustations in some of the high temperature fumaroles where hydrofluoric acid was detected. Much of the aluminum, however, was magnetite were precipitated by hydrolysis, and in all probability were better protected from the leaching action of acid condensates by high temperatures throughout much of the life of the fumarole.

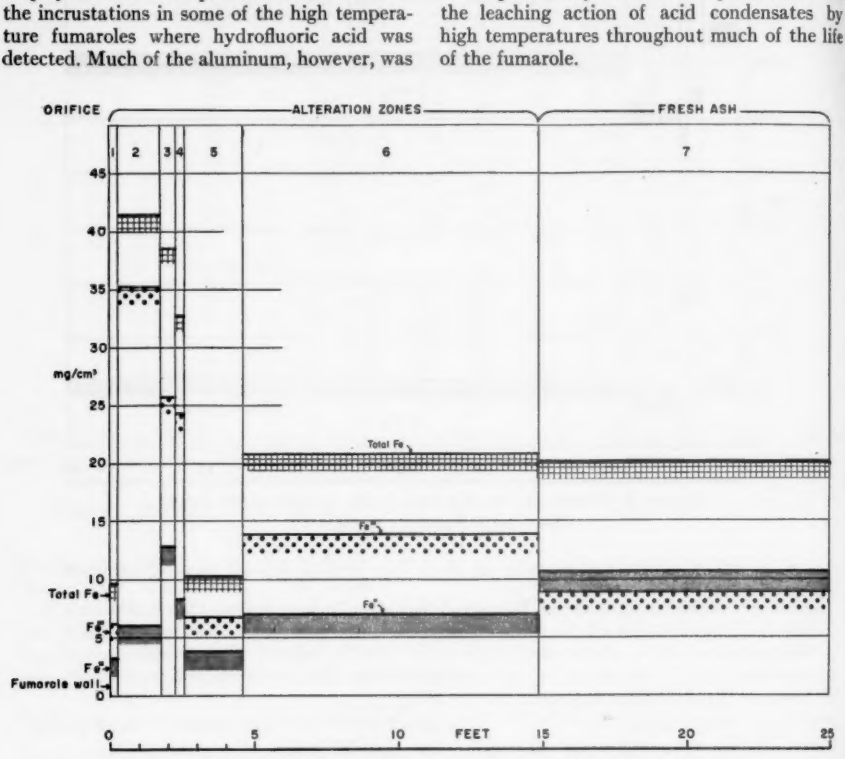

FIGURE 5.—VARIATION OF FERROUS, FERRIC, AND TOTAL IRON IN ALTERATION ZONES
Described in Figure 3. (in mg/cm³)

fixed as albite, probably by recrystallization of the glass in the hot-gas phase. Albite is abundant in zone 1 and present in readily identifiable amounts in zone 2; minor hydromica and kaolinite are also present.

Both magnetite and hematite have been observed under the microscope in the crust of zone 1, but the amount of iron present is very minor. Virtually all iron probably was eliminated from this crust at an early stage, but hematite and magnetite were formed by hydrolysis of volatile iron chloride as the fumarolic emanations cooled. It is quite possible that some of the iron thus deposited may have been dissolved by late acid condensate in the waning stages of the fumarole's activity. As shown in Figure 5, the maximum content of iron is in zone 2, where more of the hematite and

The notable increase in iron in zones 4 and 3 over that in zone 5 probably reflects in some part the precipitation through evaporation of the liquid solutions as with the alumina. It is interesting to observe the drop in total iron between zones 6 and 5 and the evidence of the oxidizing character of both the liquid- and gas-phase solutions, furnished by the increase in the ratio of ferric to ferrous iron through the zones of increasing alteration. The maximum is reached in zone 2 where the ratio of ferric to ferrous iron is more than 6 to 1; in this zone where probably air and steam moved toward the throat from the surrounding area, nearly all the iron present is in the form of ferric oxide with only a minor amount of magnetite, whereas in the lining of the fumarole throat (zone 1) there is more magnetite than hematite.

The loss of magnesium and calcium in zones 6 and 5, shown in Figure 6, is readily explained by the action of hot acid waters, and the sharp increase in zones 4 and 3 by the general mechanism of boiling suggested above. It appears that both magnesium and calcium were attacked by hot acid gases in zones 1 and 2, but as would be expected, the attack was more vigorous in the throat than in zone 2 (Fig. 6). Sodium and potassium show a very similar pattern to that of calcium and magnesium, but there is evidence that potassium was attacked to a far less extent by the liquid solutions than was sodium (Fig. 6) and that some potassium was added in zone 2; the presence of hydromica in this zone as an alteration product of biotite and plagioclase probably reflects this addition of potassium. Most of the sodium in zone 1 is in albite, which the X-ray spectrograph shows is abundant in this zone. Albite is very resistant to the attack of halogen acids at high temperatures, in contrast to other sodium-bearing silicates (Wichers, Schlecht, and Gordon, 1944).

As shown in Figure 7, the increase in chemically combined water reaches a maximum in zone 4, although total water is at a maximum in zone 3; these peaks for water correspond closely with the peak for alumina and reflect argillic alteration and development of clay minerals (allophane, halloysite, hydromica, or "illite") in the transitional zones between gas-phase and liquid-phase reactions.

It is worthy of note that carbon dioxide was not found in any of the samples by the standard absorption method using 5-gm analytical subsamples and therefore was present in less than 100 ppm quantities. The amount of sulfur varies in the different zones, but shows a sharp peak in zone 1 where it was fixed as sulfate by lead, calcium, and barium. A very minor amount of sulfur is combined as iron sulfide in zone 2, but the amount of ferrous iron and the total amount of sulfur in this zone is insignificant. Elsewhere the sulfur is present as sulfate, chiefly in gypsum.

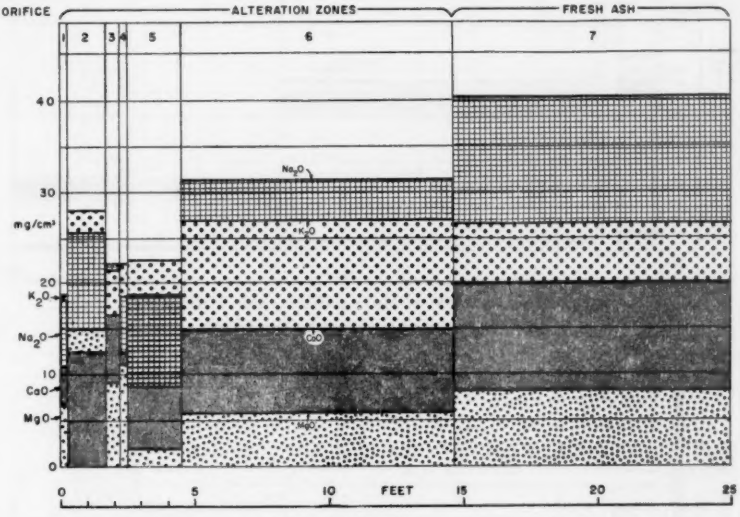

FIGURE 6.—VARIATION OF Na_2O, K_2O, MgO, AND CaO IN ALTERATION ZONES Described in Figure 3. (in mg/cm³)

Although the gases contained both chlorine and fluorine, and were especially rich in hydrochloric acid, the amount of chlorine present in the altered material is little more than in the fresh ash and reaches a maximum of 2.3 mg/cm³ in zone 2 as compared with 1.5 mg/cm³ in the fresh ash of zone 7 (Fig. 8). Fluorine, on the other hand, has a double peak, one in the first thin crust in the throat of the fumarole, and the other in zone 4 where it is presumed the aqueous acid condensates were boiling. It is possible that this fluorine is largely bound up in the lattice of the clay minerals that are abundant in this zone.

The minor constituents show two general

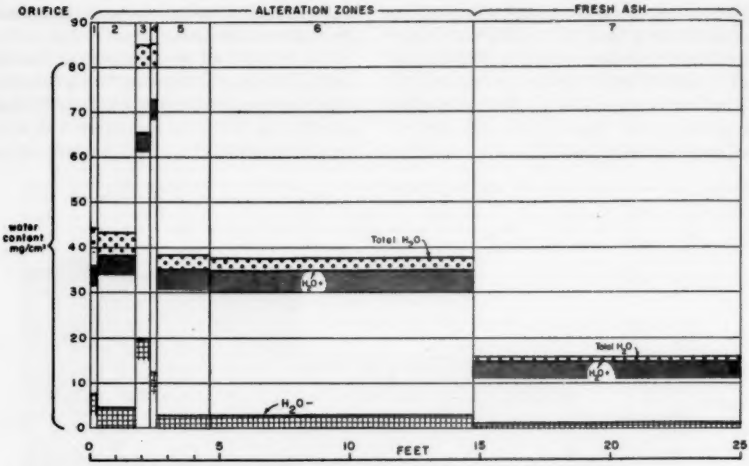

FIGURE 7.—VARIATION OF H_2O-, H_2O+, AND TOTAL H_2O
In zones described in Figure 3. (in mg/cm³)

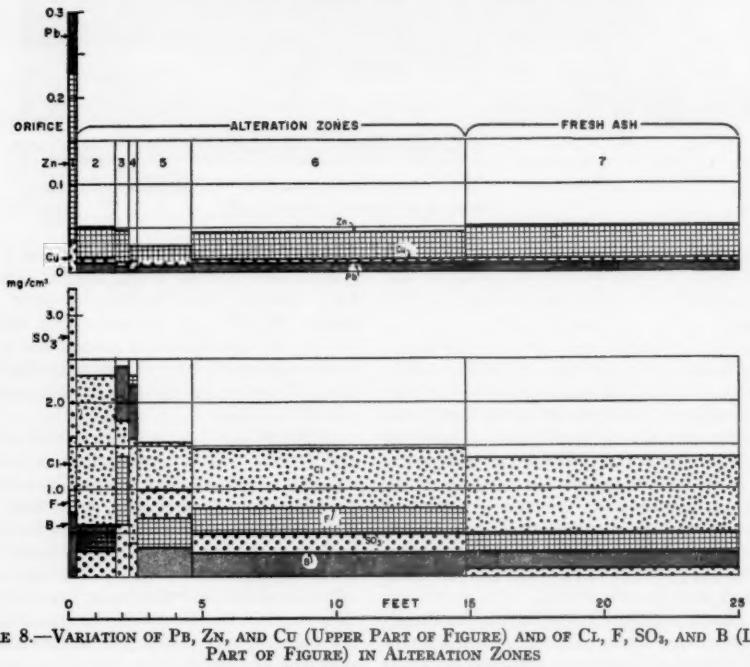

FIGURE 8.—VARIATION OF PB, ZN, AND CU (UPPER PART OF FIGURE) AND OF CL, F, SO_3, AND B (LOWER PART OF FIGURE) IN ALTERATION ZONES
Described in Figure 3. (in mg/cm³)

behavior patterns: lead, zinc, copper, and arsenic have a strong maximum in zone 1 with a minimum in zone 5, except for lead which has its minimum in zone 4 (Fig. 8). Another group of elements shows a strong maximum in zone 4, or 3 and 4, with their chief minimum in zone 5 and another minimum in zone 1. These elements include cobalt, nickel, and scandium. Although

boron shows a steady increase from zones 1 and 2 to 3 and 4, it shows no change in zones 7, 6, and 5 (Fig. 9). It appears that little boron was leached from the minerals in the pumice or from the glass, but that it was added from the fumarolic emanations and had the optimum

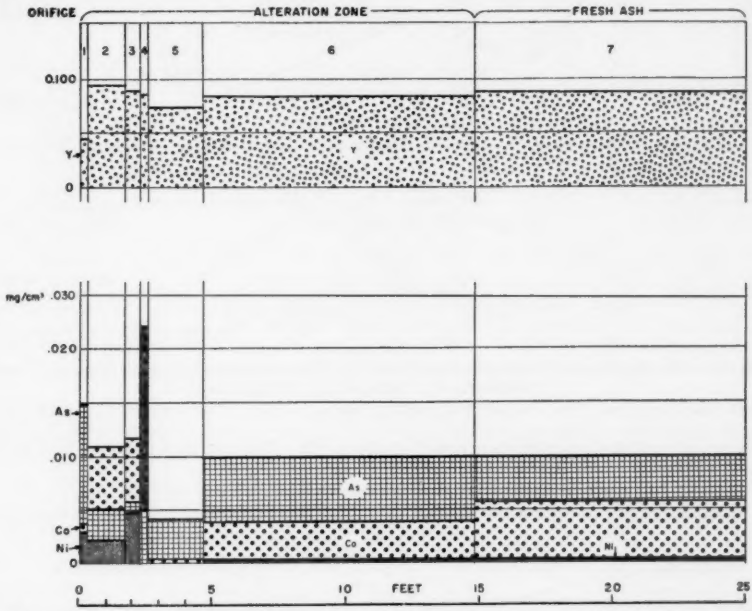

FIGURE 9.—VARIATION OF Y (UPPER PART OF FIGURE) AND OF Co, Ni, AND As (LOWER PART OF FIGURE) IN ALTERATION ZONES
Shown in Figure 3. (in mg/cm³)

conditions for precipitation at the gas-liquid interface.

COMPARISON OF SULFUR- AND HALOGEN-ACID ALTERATIONS

Studies of the effect of alteration caused by sulfur acids are relatively few, but the work of Rittmann (1934) at Solfatara, Italy, and Anderson (1935) at Lassen Peak, give us information that suggests certain differences between the attack of the halogen acids and the sulfur acids on rock (Tables 3, 4; Figs. 10–13).

Although the three kinds of rocks that are the subjects of these alteration studies are closely related, unfortunately they are not identical; latite and trachyte furnish the data for the sulfur-acid studies, and the parent material in the Valley of Ten Thousand Smokes is pumice and ash composed of intimately mingled andesitic and rhyolitic ejecta. The greater degree of crystallinity of the latite and trachyte in contrast with the rhyolitic ash probably makes them somewhat more resistant to alteration than the glassy material of the valley pumice, but on the other hand, the more silicic composition of the pumice would tend to make it more resistant to alteration than the somewhat less silicic trachyte and latite.

Trachyte at Solfatara, Italy, shows a continually decreasing content of silica from the fresh rock to the innermost zone of an active fumarole, whereas the silica content in an altered latite boulder that was taken out of a boiling hot spring on Lassen Peak (with a free sulfuric acid content of approximately 0.04 per cent) showed some redeposition of silica in the porous outermost intensely leached zone. Although it is realized that the comparison of one suite of samples with two others has no statistical validity, the similarities and differences brought out by comparison of the three studies is suggestive. The three sets of analyses show the greatest contrast in the behavior of silica and alumina; as might be expected, the halogen acids are more effective than the sulfur acids in

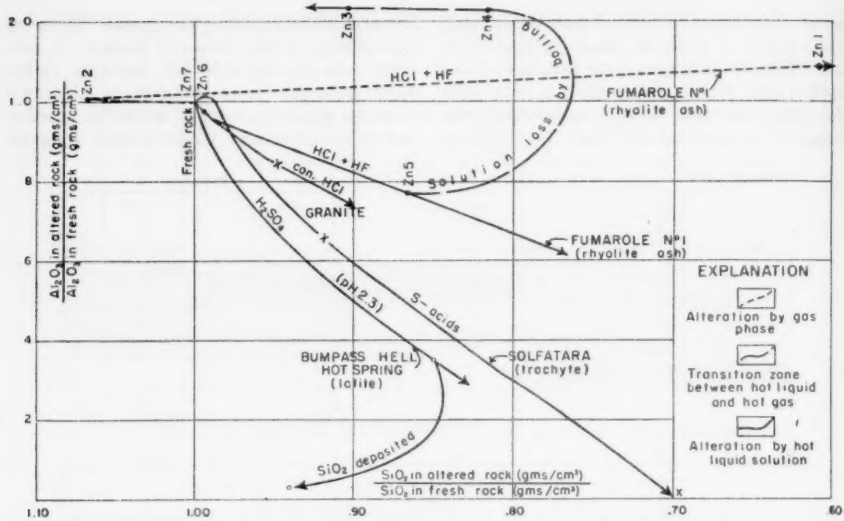

FIGURE 10.—COMPARISON OF ALTERATION EFFECTS OF HALOGEN AND SULFUR ACIDS—CHANGE IN ALUMINA CONTENT AS A FUNCTION OF SILICA LOSS

(Basic data in mg/cm³). The direction of increasing intensity of alteration is shown by the arrows; some late stage introduction of material occurred in the intensely altered zones of the Bumpass Hell material (Anderson, 1935) but not in the Solfatara suite (Rittmann, 1934). The effect of boiling some fresh granite in concentrated HCl for 1 hour (Blanche and Passarge, 1925) is also shown.

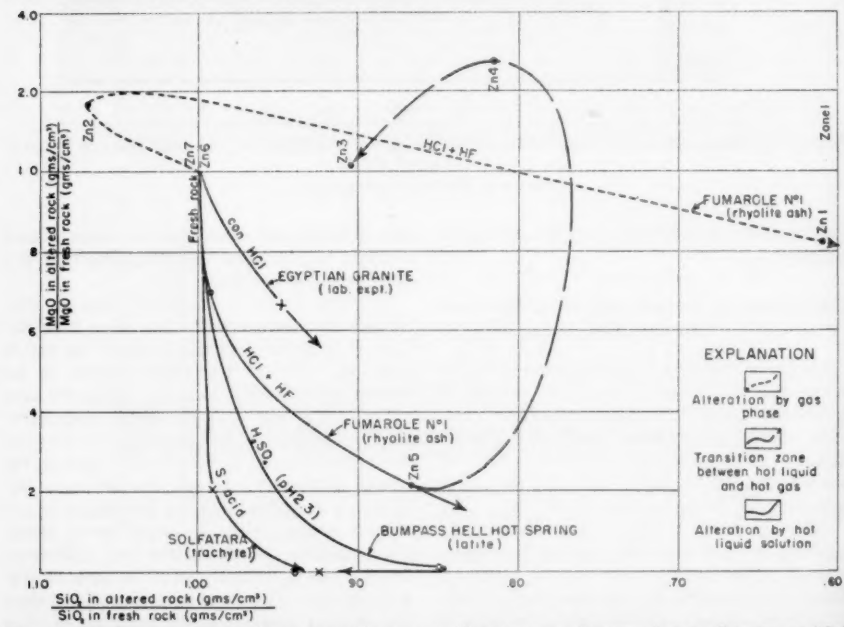

FIGURE 11.—COMPARISON OF ALTERATION EFFECTS OF HALOGEN AND SULFUR ACIDS—CHANGE IN MgO CONTENT AS A FUNCTION OF SILICA LOSS

See Figure 10 explanation also.

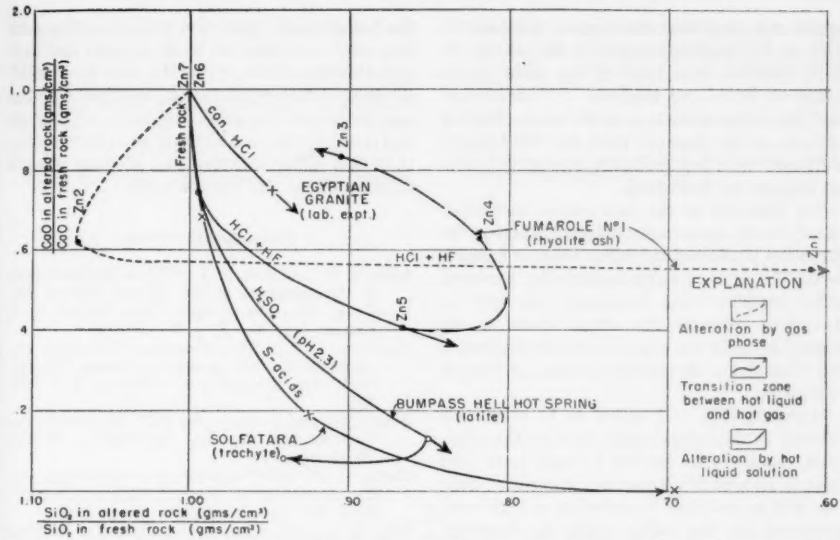

FIGURE 12.—COMPARISON OF ALTERATION EFFECTS OF HALOGEN AND SULFUR ACIDS—CHANGE IN CaO CONTENT AS A FUNCTION OF SILICA LOSS

See Figure 10 explanation also.

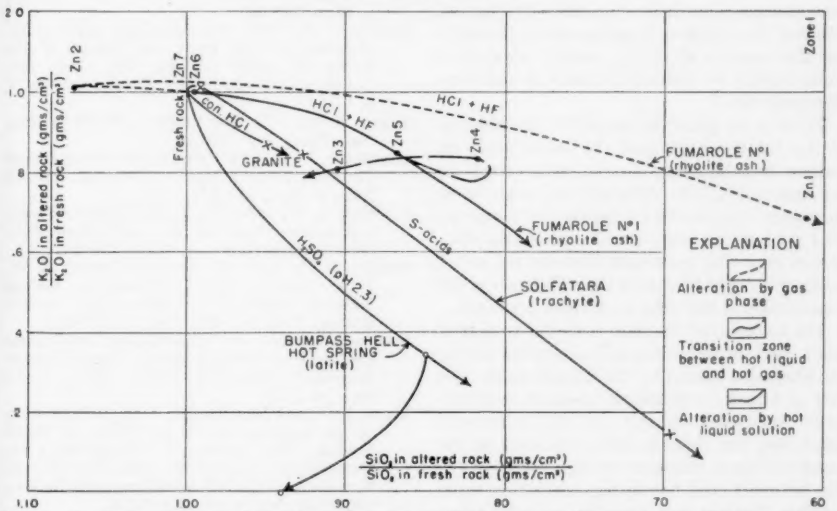

FIGURE 13.—COMPARISON OF ALTERATION EFFECTS OF HALOGEN AND SULFUR ACIDS—CHANGE IN K_2O CONTENT AS A FUNCTION OF SILICA LOSS

See Figure 10 explanation also.

removing silica in stages of alteration that are roughly comparable in the degree of leaching of the other oxides. In the graphs shown in Figures 10–13, the ratio of silica per cm³ in the altered rock to that in the fresh rock has been used as abscissas, and the ratio of the other oxides in the altered and fresh rocks has been used as ordinates to show the changes of other oxides relative to the losses or gains of silica.

As shown in Figure 10, the effect of both

liquid- and gas-phase reactions of the halogen acids on the alumina content of the pumice, is quite different from that of hot sulfur acids acting on latite and trachyte. It would seem that the sulfur acids are much more effective solvents of the alumina than are the halogen acids and have less tendency to re-precipitate the alumina by hydrolysis.

The behavior of the iron oxides (not illustrated) is not appreciably different whether the alteration is effected by sulfur acids or halogen acids. The ferrous oxide apparently decreases rather steadily with increasing intensity of alteration, whereas the ferric oxide shows marked gains in the zones of weaker alteration and then drops off rapidly in zones of intense alteration.

Magnesia (Fig. 11) seems to be much less affected by the halogen acids than by the sulfur acids, especially by the hot halogen gases, and there is an actual increase in magnesia in zone 2 as well as in 4 and 3, probably at high temperatures. In the sulfur acids, by contrast, magnesium sulfate apparently disappears rapidly from the system. The behavior of calcium (Fig. 12) is similar but less striking than that of magnesium in the two different types of solution, but calcium is impoverished throughout the zones of alteration, except where it is concentrated by boiling in zones 3 and 4 of Fumarole No. 1.

There is no great difference in the behavior of the halogen acids and the sulfur acids on sodium (not illustrated) or in their attack on potassium (Fig. 13). Although the analyses of the zones adjacent to Fumarole No. 1 suggest that the halogen acids are somewhat less effective in removing potassium than are the sulfur acids, this could be due to the difference in the composition of the three rock types involved.

The behavior of titanium is similar to that of silica, both in the sulfur-acid alteration and in the alteration caused by the halogen acids. The rate of attack on titanium, however, is apparently somewhat greater in the sulfur-acid alteration, but there is little indication of the precipitation of titanium through hydrolysis in the fumarolic and hot springs alteration types studied. The fact that titanium is readily taken into solution in both gas and liquid phases and transported out of the system, suggests that somewhere it would normally be precipitated by hydrolysis if the alteration were taking place at depth.

In summary, then, it can be said that both the halogen-acid alteration and the sulfur-acid alteration are similar in most respects and that probably all constituents of the rock are leached in zones of intense alteration, but that alumina and magnesia are more subject to hydrolysis and precipitation in a high halogen environment than in a sulfur-acid medium, whereas silica is more mobile in the halogen acids.

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MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, DECEMBER 26, 1956

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 68, PP. 1605–1636, 13 FIGS. DECEMBER 1957

ORIGIN OF THE CORUNDUM DEPOSITS OF RENFREW COUNTY, ONTARIO, CANADA

BY H. D. CARLSON

ABSTRACT

In Renfrew County corundum is erratically distributed through a banded complex of rocks rich in scapolite, andeclase, and nepheline but is more abundantly developed and uniformly distributed in contact zones between this banded complex and a younger hybrid alkaline syenite.

The scapolite-andeclase-nepheline gneiss complex may have formed by (1) the metasomatic alteration of intercalated calcareous and aluminous metasediments, or (2) the intrusion of sill-like masses of an anorthositic magma into such metasediments. No positive evidence supporting either of these hypotheses was obtained in this study. In both hypotheses it is assumed that some corundum formed by the transformation of alumina-rich parts of the metasediments into corundum-bearing rock either by metasomatism or by magmatic assimilation.

The hybrid alkaline syenite appears to have developed by metasomatism of the rocks of the earlier complex. In this process potassium and silica were added, and lime, soda, and alumina were released from the scapolite, andeclase, and nepheline rocks. Much of the corundum in the contact zones is attributed to the crystallization of some alumina released from the older rocks during the transformation into syenite. Some of this alumina may have migrated, with the hydrothermal solutions responsible for the metasomatism, to loci favorable for the development of corundum-rich pegmatitic facies of the hybrid alkaline syenite.

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Introduction

From 1900 to 1921 corundum was mined from 14 workings in southwestern Renfrew County and adjacent parts of Hastings County in southeastern Ontario. During the field seasons of 1951 and 1952 the writer was employed by the Ontario Department of Mines as field assistant to Dr. D. F. Hewitt in mapping portions of this area. In the course of this work the corundum deposits were examined and mapped in detail; particular emphasis was placed on the Craigmont and Klondike workings as these are much more extensive than all the others combined. Of about 400 samples collected nearly 200 thin sections and 27 new chemical analyses were made of the corundum-bearing and associated rocks.

Acknowledgments

The writer wishes to express his indebtedness to Dr. D. F. Hewitt of the Ontario Department of Mines for suggesting the problem and for much helpful advice and criticism during the field examinations. The Ontario Department of Mines supported much of the field work and provided 7 chemical analyses and 50 thin sections of the rocks. The Geological Survey of Canada provided a grant for 20 chemical analyses of the rocks. Mr. L. Moyd kindly provided a detailed geologic and topographic map of the corundum workings. The laboratory investigations were carried out in the Department of Geological Sciences, Queen's University, under the direction of Professors J. E. Hawley and J. W. Ambrose. The writer is grateful for their encouragement and criticism during the course of the research. A National Research Council Fellowship was held by the writer during the academic year 1952–1953. Messrs. L. Moyd, J. L. Gillson, and A. E. J. Engel have read the manuscript critically and offered many helpful suggestions for its improvement.

Previous Work

Many investigators have examined the corundum deposits of Renfrew County since their occurrence was first reported in October 1896, by W. F. Ferrier (1896, p. 116) of the Geological Survey of Canada. The following writers have expressed opinions on the origin of the corundum: Miller (1899, p. 205), Adams and Barlow (1908; 1910), Barlow (1915), Thomson (1943, p. 21), Satterly (1944, p. 33), and Moyd (1949, p. 736). In summation, three main hypotheses have been advanced for the origin of the corundum: (1) corundum crystallized as a normal pyrogenetic mineral from a highly aluminous liquid magma; (2) corundum formed as a result of the replacement of nepheline rock by syenite; or (3) corundum formed as the result of the metasomatic alteration of metasedimentary facies.

General Geology

Southeastern Ontario, the southern Laurentian Highlands of Quebec, and the Adirondack region in New York State form the Grenville subprovince of the Precambrian Canadian Shield. In all sections of the subprovince the succession of formations is generally similar: first, a series of predominantly metasedimentary rocks with minor lava flows in places, termed the Grenville Series; these have been intruded by gabbro, diorite, and anorthosite; then followed a period of the development of large areas of granitic and syenitic gneisses and the

intrusion of much granite pegmatite; minor intrusion of diabase dikes followed the emplacement of the granitic rocks. Some writers have suggested the presence of a granite gneiss, the Laurentian, which is older than the basic intrusives, but this is not established as fact.

A large belt of alkaline rocks in the Haliburton-Bancroft district of southeastern Ontario has attracted the attention of many petrologists. This belt extends northeastward for more than 70 miles from the vicinity of Gooderham in Glamorgan township, Haliburton County to the northeast corner of Lyndock township, Renfrew County. The characteristic rocks of this belt, according to Adams and Barlow (1909), are of three main types, as follows:

(1) Nepheline gneisses. These rocks present extreme variations in the relative proportions of their constituent minerals; they pass, by a decrease in the amount of plagioclase present into rocks composed exclusively of nepheline and ferro-magnesian minerals, or into varieties composed almost exclusively of nepheline, or into very basic varieties composed almost exclusively of mafic constituents.

(2) Plagioclase-rich rock (white alkali syenite). This differs from the nepheline gneisses in the occurrence of nepheline merely as an accessory constituent or by the absence of this mineral. The rock is composed of plagioclase (albite, oligoclase, or andesine) and mafic constituents; the latter is usually in very subordinate amounts.

(3) Red alkaline syenite. This rock consists of variable proportions of microcline and plagioclase (oligoclase-andesine).

The rocks of these three groups grade imperceptibly into one another.

The zone of predominantly syenitic rocks, in which the corundum deposits of Renfrew County occur, lies within and near the eastern end of the Haliburton-Bancroft belt of alkaline rocks. Corundum is present in minor amounts at several points throughout this alkaline belt, though nowhere in the region is this mineral so abundantly developed as in the deposits described in this report. Accordingly, no postulated origin of the corundum deposits seems permissible which is incompatible with the origin of the alkaline rocks of the region as a whole.

Hypotheses for the origin of these alkaline rocks fall into two main groups:

(1) Magmatic. The alkaline rocks, formed from intrusive molten magmas. These may have been produced through limestone assimilation and syntexis by granite magmas, as proposed by Daly, or by the fractional crystallization of basaltic magma, as suggested by Bowen, or by some as yet undiscovered process.

(2) Metasomatic. The alkaline rocks are regarded as metasomatically altered metasediments of the Grenville Series.

D. F. Hewitt (1953) has described in considerable detail the general geology of the area in which the corundum deposits occur.

Corundum Deposits

The Klondike cuts are on the southwest end of Robillard Mountain, Lot 2, Concession 19, Raglan township, and the Craigmont cuts are on the south flank of the east end of the same hill, Lots 3 and 4, Concessions 18 and 19, Raglan township. Robillard Mountain, more than 1500 feet in elevation, rises about 500 feet above the adjacent sand plains along the York River in the northwest corner of Raglan township. The south slope trends roughly east-west for about 1 mile.

Corundum was mined from more than 20 open-cut workings on the south slope and from 11 cuts on the southwest end of the hill. The cuts range in size and depth from short ledges 15–20 feet long and 2 or 3 feet deep up to large quarries such as the upper pond cut at Craigmont, which is 500 feet long with a maximum width of 100 feet and a maximum depth of 40 feet. The easternmost cut at the Klondike workings is 320 feet long with a maximum width of 100 feet and a maximum depth of 60 feet. The majority of the cuts are not deeper than 20 feet, and in many the depth does not exceed 10 feet. Apparently the working procedure was to start mining outcrops of corundum-rich rock and to follow these down until the corundum content was below ore grade.

Of the total Canadian corundum production of 24,800 tons 84 per cent has come from the Craigmont and Klondike cuts. Average grade in these two workings was 6–7 per cent corundum.

No other known corundum deposit in the area is comparable in size and extent to those of the Craigmont and Klondike workings. These deposits are described by Hewitt (1953). The geology of these deposits is similar to that on Robillard Mountain, and they will not be described separately, except where some particular feature is of special interest.

Corundum-Bearing and Associated Rocks

General Statement

The rocks exposed in the corundum workings may be divided into the following groups:

(1) Granite and syenite pegmatites
(2) Granite-syenite gneiss complex
  (a) Granite-gneiss and migmatite
  (b) Quartz-arfvedsonite syenite
  (c) Hybrid alkaline syenite (± corundum)
(3) Scapolite - andeclase - nepheline gneiss complex
  (a) Leuco-nepheline gneiss (± corundum)
  (b) Andeclase rock (± corundum)
  (c) Scapolite rock (± corundum)
(4) Amphibolite

Corundum occurs erratically in irregular, generally elongate, lenticular zones in the scapolite rock, the andeclase rock, and the nepheline gneiss. The rock in these zones is petrographically identical with the interzonal material except for the presence of the corundum, which may range from 1 or 2 per cent to more than 25 per cent in a single zone. Thus the corundum-bearing portions of the scapolite andeclase-nepheline gneiss complex are not sharply defined. Corundum appears to be more abundantly, and certainly more generally, developed in and along the contact zones between the hybrid alkaline syenite and the various members of the scapolite-andeclase-nepheline gneiss complex; altered inclusions of the latter in the syenite are usually rich in corundum. Corundum is also present in certain coarse-grained, inequigranular, pegmatitic phases of the hybrid alkaline syenite. In all these facies the corundum occurs as an integral constituent, and its origin cannot be considered apart from the origins of the rocks containing it.

Age Relations

Age relations among the various rock types, for the most part, are well established. The metasedimentary amphibolites, the oldest rocks in the workings, are cut by the hybrid alkaline syenite but were not seen in contact with the other rock types. Relationships between the nepheline gneiss and the andeclase and scapolite rocks in the Craigmont and Klondike workings are obscured by the extensive development of the hybrid alkaline syenite. Elsewhere, however, especially at Reid Lake, they are intimately and conformably interbanded and have gradational contacts. This close field association suggests that the nepheline, andeclase, and scapolite rocks had related modes of formation. Petrographic studies support this view but indicate that the andeclase rock formed later than the scapolite rock and that the nepheline gneiss formed later than the andeclase rock, although age differences may be slight.

The granite and syenite gneisses appear to be contemporaneous, for they grade into one another along and across the strike of the zones in which they occur. The hybrid alkaline syenite cuts the nepheline gneiss, the andeclase and scapolite rocks, and the amphibolite and is therefore younger than these rocks. The granite and syenite pegmatites occur in well-defined dikes which cut all the other rocks in the workings.

Occurrence

The rocks exposed on the south slope of Robillard Mountain consist of a number of isolated, discontinuous, lenticular bands, lenses, and irregular, elongate masses of amphibolite, andeclase and scapolite rocks, and nepheline gneiss which are in rough parallel alignment with each other; these are enclosed in a conformably banded hybrid alkaline syenite complex. A generalized hypothetical cross section of a part of the south slope of Robillar Mountain (Fig. 1) shows the banded nature of the rock sequence and the relationships between the major lithologic members.

To the north the banded corundum-bearing and syenitic rocks are underlain by and grade into granite gneisses and migmatites which are exposed on the top and the east slopes of the hill. In a cut at the bottom of the south slope leuco-granite gneisses overlie and grade into hybrid alkaline syenites. This suggests the probability that at depth the corundum-bearing rock zone is overlain by and grades upward into granite gneisses. All available evidence supports this hypothesis; thus the corundum-bearing and syenitic rock sequence appears to be a narrow, banded zone probably no more than 300 feet thick that forms a thin veneer on the south slope of Robillard Mountain.

All the foregoing rock types are cut by numerous small dikes, stringers, and irregular masses of pink to yellow-brown, granitic to syenitic pegmatite.

Structural Geology

The banded structure of the rock sequence exposed on the south slope of Robillard Moun-

tain strikes roughly N. 80°W. and dips about 30°S. It parallels the regional structural trend. Locally, the strike of the bands deviates from the average by as much as 20°, and the dip by as much as 10°, where minor, low, open folds

positions of the plagioclases were determined on thin sections with the four-axis universal stage. The determinations of the scapolite compositions were made by oil-immersion methods on mineral fragments.

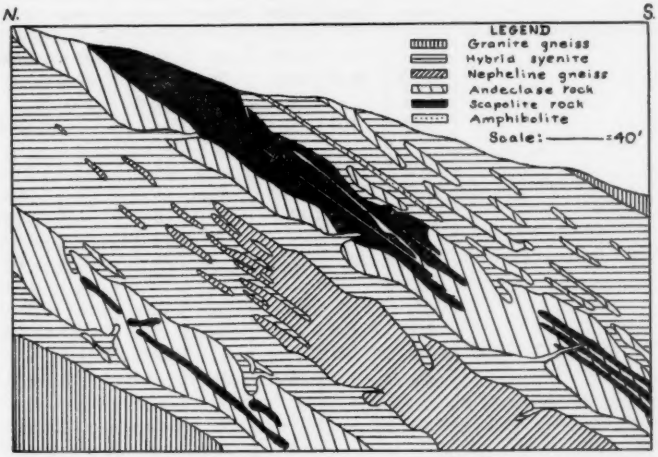

FIGURE 1.—A GENERALIZED, HYPOTHETICAL, NORTH-SOUTH CROSS SECTION THROUGH PART OF THE SOUTH SLOPE OF ROBILLARD MOUNTAIN

Showing the banded structure of the corundum-bearing rocks and illustrating the main field relationships between the various lithologic facies.

are superimposed on the general structure. These appear to have no significance with respect to the distribution of the various rock types or to the distribution of corundum in the sequence.

Of the three sets of joints in the nepheline gneiss one strikes N. 60°W., another strikes N. 30°E., and a third strikes N. 35°W.; all sets dip vertically. Of the two sets of joints in the hybrid alkaline syenite complex one strikes N. 75°W., the other strikes N. 40°E.; both sets dip vertically.

Small shears, breaks, and faults are common in the corundum workings, but the extent and direction of movement, if any, is unknown. The joints, shears, and faults appear to have formed after the development of the hybrid alkaline syenite, for they cut this facies as well as the rocks of the earlier complex.

Petrography and Chemical Composition

The mineral compositions of the corundum-bearing and associated rocks were estimated in the field and from thin sections. The com-

The 27 chemical analyses of the corundum-bearing and associated rocks were recast into modes using ideal molecular formulae for the minerals known to be present in the rocks. The calculation of modes was preferred to the calculation of norms, since the latter yielded hypothetical mineral molecules unlike the minerals in the analyzed samples. The modes could not be determined by Rosiwal analyses of thin sections of the samples because of the coarse grain size and nonhomogeneous character.

Amphibolite

Dark-gray to black amphibolite occurs as thin lenticular bands, generally less than a foot thick, conformably intercalated in the banded structure of the rock sequence. The constituent minerals (Table 1, column 1) are fresh and clear, with only minor amounts of secondary minerals developed.

A few narrow lenses of schistose biotite-rich rock are intercalated in the banded sequence. This rock varies in composition from more

TABLE 1.—ESTIMATED MINERAL COMPOSITIONS OF THE CORUNDUM-BEARING AND ASSOCIATED ROCKS

Per cent composition

	Amphibolite		Nepheline gneiss		Andeclase rock		Scapolite rock	
	Range	Average	Range	Average	Range	Average	Range	Average
Corundum	..	..	15–0	5?	25–0	6?	20–0	3?
Plagioclase	39–55	46.0	26–6	18.0	95–54	80.0	..	..
Microcline	..	..	3–0	1.0	11–0	3.0	..	..
Scapolite	1–0	1.0	..	..	..	..	98–60	85
Nepheline	..	..	81–55	67	..	..	..	..
Magnetite	1–2	1.0	2–1	1.5	16–0	2.0	20–0	3.0
Biotite	33–3	16.0	2–0	tr.	16–0	1.5	6–0	1.0
Muscovite	..	..	10–1	5.0	6–0	1.5	5–0	1.0
Pyroxene	..	..	..	..	5–0	1.0	34–0	2.0
Hornblende	12–55	34	..	..	31–0	1.5	5–0	1.0
Garnet	..	..	..	..	..	..	15–0	2.0
Epidote	..	..	..	..	..	..	25–0	2.0
Apatite	2–1	1.0	..	..	3–0	0.5	2–0	tr.
Titanite	3–0	1.5	..	..	5–0	1.0	3–0	tr.
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Pyrite	..	..	..	..	..	..	..	tr.
Spinel	..	..	..	..	..	..	tr.	tr.
Sec. white mica	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Carbonate	tr.	tr.	2–0	1.0	3–0	1.0	2–0	1.0
Chlorite	tr.	tr.	..	..	2–0	0.5	tr.	tr.
Hydronephelite	..	..	3–0	1.0	..	..	..	..
Gieseckite	..	..	2–0	1.0	..	..	..	..
		100.0		100.0		100.0		100.0

PLAGIOCLASE COMPOSITION

	Average	Number	Average	Number	Average	Number	Average	Number
An_{20} to An_{28}	An_{26}	3	An_{25}	4	An_{24}	8	..	..
An_{27} to An_{33}	An_{30}	3	An_{28}	13	An_{30}	13	..	..
An_{34} to An_{37}	..	..	..	..	An_{35}	3	..	..

SCAPOLITE COMPOSITION

Me_{61} to Me_{55}	..	..	..	..	..	..	Me_{59}	2
Me_{54} to Me_{50}	..	..	..	..	..	..	Me_{51}	5
Me_{49} to Me_{45}	..	..	..	..	..	..	Me_{47}	10
Me_{44} to Me_{40}	..	..	..	..	..	..	Me_{41}	4

The rock is medium-grained equigranular with a schistose texture; the mica flakes and hornblende prisms are in parallel alignment. Many plagioclase grains show strain shadows and slightly bent twin lamellae.

The amphibolite exposed in the corundum workings is identical in appearance and lithology with the metasedimentary amphibolites of the area and probably is of the same derivation. Wherever seen it is enclosed in hybrid alkaline syenite.

than 85 per cent biotite with more than 10 per cent apatite and no feldspar to less than 50 per cent biotite with predominant plagioclase (oligoclase-andesine). Similar rocks occur in the Blue Mountain nepheline rock mass near Lakefield, Ontario, as narrow lenses which cut across the gneissic structure of the nepheline rock. In this locality they are considered by

Derry (1951, p. 31–40) to be metamorphosed mafic dikes. It is possible that the biotite-rich lenses in the corundum workings had a similar origin, although they show no positive evidence of intrusion, such as dilational, cross-cutting relationships to the enclosing syenite complex. They may have been thin sills or dikes as proposed by Adams and Barlow (1909, p. 59).

Scapolite-Andeclase-Nepheline Gneiss Complex

The term andeclase rock is an abbreviation of andesine-oligoclase-rich rock. The word andeclase was proposed by Winchell (1946, p. 358) to designate plagioclase in the compositional range An_{30} to An_{40}. Since the rock consists predominantly of such feldspar its name is an appropriate one.

The andeclase and nepheline rocks are light gray or almost white; the scapolite rock is green or gray green. The mineral compositions of the three members of the complex, according to rough estimates made on the basis of field and thin section investigations, are given in columns 2, 3, and 4 of Table 1. All the constituent minerals are fresh and clear; alteration to secondary products was slight in most specimens examined.

The corundum-bearing zones are haphazardly distributed, not confined to a particular horizon in the banded rock sequence. Corundum occurs in the andeclase and scapolite rocks as bronze or green, stubby, euhedral grains 1 mm–5 cm in diameter; in the nepheline gneiss this mineral is present as long, slender, euhedral, hexagonal, barrel-shaped, bronze to green crystals, < 1 mm–10 cm long. Most grains and crystals of corundum have partial to complete halos or selvages of muscovite surrounding them. The muscovite appears to have formed at the expense of the corundum and in places seems to have replaced it, since large, euhedral, hexagonal, pseudomorphs of muscovite after corundum occur in the complex. The selvages range in thickness from thin films to thick shells around a corundum core. Where the muscovite halos are thin or absent, the corundum grains and crystals have mutual boundaries with the plagioclase, scapolite, or nepheline grains.

Many of the anhedral plagioclase grains in the andeclase and nepheline rocks show strain shadows and slightly bent twin lamellae. There appear to be two generations of plagioclase in the nepheline gneiss: an older plagioclase with a composition ranging from An_{25} to An_{34} and a younger generation with a composition ranging from An_4 to An_{18}. The latter predominates quantitatively and appears to have developed by replacement of the older feldspar.

Nepheline occurs in large to medium-sized anhedral grains which are generally fresh and clear and show no evidence of crushing such as strain shadows or mortar structure. They tend to be larger than the associated plagioclase grains. The lack of crushing in the nepheline grains and its presence in the associated plagioclase grains suggests that the nepheline formed after the deformation of the plagioclase had ceased.

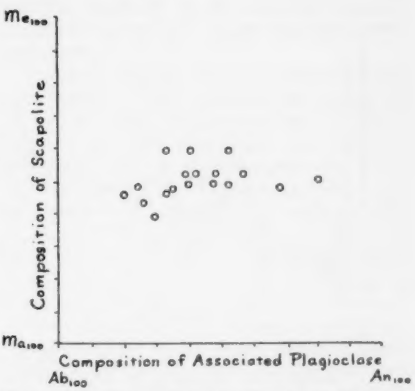

FIGURE 2.—COMPOSITION OF SCAPOLITE PLOTTED AGAINST COMPOSITION OF ASSOCIATED PLAGIOCLASE
In hybrid andeclase-scapolite rocks.

Scapolite in the scapolite rock occurs as rounded anhedral grains which have smooth curving boundaries, in contrast to the interlocking plagioclase grains in the andeclase rock and plagioclase and nepheline grains in the nepheline gneiss. The scapolite rock is closely associated with the andeclase rock, and hybrid mixtures of the two are common.

The plagioclase in these hybrid zones ranges in composition from An_{20} to An_{80}, whereas in the andeclase rock the plagioclase ranges in composition from An_{20} to An_{37}, with most of it about An_{30}. The range of the meionite content of the scapolite in these hybrid rocks (Fig. 2) is the same as in the main mass of the scapolite rock and shows no variation with changes in the anorthite content of the accompanying plagioclase. Barth (1952, p. 283–284) has shown that the composition of scapolite developed through the alteration and replacement of plagioclase by carbonate-bearing hydrothermal or deuteric solutions should be anal-

agous to that of the plagioclase replaced. The evidence summarized in Figure 2 does not support the development of the scapolite by replacement of the plagioclase.

In the specimens examined the composition of the plagioclase differed with the relative

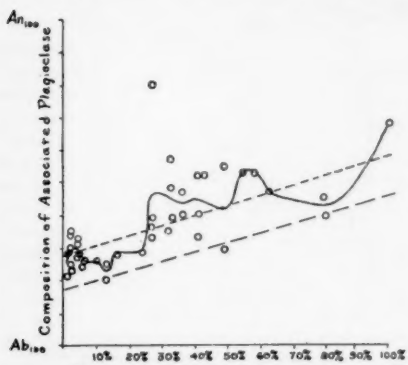

FIGURE 3.—AMOUNT OF SCAPOLITE IN THIN SECTIONS PLOTTED AGAINST COMPOSITION OF ASSOCIATED PLAGIOCLASE

In hybrid andeclase-scapolite rocks.

abundance of scapolite in the rock; this variation is not a simple direct one, but in general, the more scapolite in the rock the higher is the anorthite content of the associated plagioclase (Fig. 3).

The meionite content of the scapolite rock is consistently higher than the anorthite content of the andeclase rock, but in the hybrid andeclase-scapolite rock the anorthite content of the plagioclase increases, more or less directly, with the increase in the amount of scapolite. The thin sections show no conclusive textural evidence as to whether plagioclase replaces scapolite or vice versa. Evidence from 37 thin sections of specimens in which plagioclase and scapolite occur together indicates a complete textural gradation in the hybrid zones between the two end-member rock types—from the sugary granular texture of the scapolite rock to the interlocking mosaic of feldspar grains in the andeclase rock. As the plagioclase content increases, the scapolite grains become smaller and less rounded; they occupy the interstices of the larger plagioclase grains and conform to all their irregularities so that the scapolite appears to be embayed and penetrated by the feldspar. The scapolite grains decrease in quantity and size until they disappear as the hybrid facies grade into andeclase rock. Such textural relationships suggest replacement of one mineral by the other but do not indicate which was replaced. However, as the evidence summarized in Figure 2 indicates, it is unlikely that the scapolite formed by replacement of the plagioclase, whereas the relationships shown in Figure 3 are most easily explained as the result of progressive local substitution of the scapolite by crystallizing plagioclase grains.

This plagioclase may have crystallized from a liquid magma which had been injected into the scapolite rock and had assimilated quantities of its chief mineral constituent along the boundary zones between the two rock types; thereby the lime content of the magma would be raised in these zones, so that more calcic plagioclase would crystallize upon its consolidation. The composition of the plagioclase would depend upon the amounts and the composition of the scapolite assimilated by the magma.

Or the plagioclase may have developed in a solid medium by the metasomatic replacement of scapolite grains through the agency of soda and silica-bearing hydrothermal solutions. The composition of the plagioclase so formed would depend, at a particular place, on the composition of the replacing solutions: this in turn would depend on the amount of scapolite the solutions had previously transformed into plagioclase; as the amount of plagioclase increases the soda and silica left in the solutions decreases and the lime and alumina increases. Thus if soda and silica-bearing solutions moved into the scapolite rock and transformed scapolite into plagioclase, the solutions would change gradually from silica and soda-rich to lime and alumina-rich. The plagioclase formed in the replacement process would correspondingly increase in anorthite content as the solutions moved through the scapolite rock.

Hornblende and pyroxene are concentrated in thin local lenses, which may contain up to 40 per cent by volume of these constituents and have a random distribution in the scapolite and andeclase rocks. These mafic lenses and thin bands parallel the banded structure of the complex and are not found in the nepheline gneiss. The pyroxene is a ferroaugite whose composition is near ferrosalite, as defined by Hess (1941, p. 515–535, 573–592). This type of pyroxene is commonly, though not exclusively, found in calcareous skarn zones. Corundum is not found in those portions of the complex that contain pyroxene and/or hornblende.

The great bulk of the scapolite-andeclase-nepheline gneiss complex contains only minor amounts of magnetite and biotite as accessory constituents. The two minerals are, in most places, closely associated. The anhedral magnetite grains have partial to complete rims of muscovite and in many places are closely associated with corundum grains. In some specimens of the andeclase and scapolite rocks a few small grains of green spinel are intergrown with magnetite and corundum. Magnetite is somewhat more abundant in the scapolite rock than in the other two facies and locally may constitute as much as 20 per cent by volume of the facies, although in other places it is absent. The mineral gathers into irregular segregations of grains, and in places lenticles of pure magnetite up to 1 foot long and 3 inches wide occur in the scapolite rock.

Garnet and epidote are quantitatively unimportant in the scapolite rock. The garnet is the andradite-grossularite variety, characteristically found in calcareous skarn zones, and is present as rounded to irregular or skeletal grains; the latter contain relatively large inclusions of scapolite. Epidote occurs in masses up to 6 inches long and 3 inches wide of medium-sized, interlocking, anhedral grains and as long thin, euhedral prisms which cut across the boundaries of scapolite grains. In one thin section euhedral epidote prisms appear to have enclosed and progressively assimilated garnets, showing interesting zoning effects—the epidote has a progressively higher birefringence away from the garnet core and becomes lighter in color. The quantity of magnetite and the nature of the garnet increase the resemblance of the scapolite rock to certain rocks of the skarn type which developed in calcareous metasediments in many parts of the Grenville subprovince. The development of epidote at the expense of garnet suggests retrogressive metamorphism. Where pyrite is present in quantity the scapolite rock weathers to a rust color.

The scapolite-andeclase-nepheline gneiss complex has a general metamorphic fabric which varies in detail both along and across the strike of the bands of the component facies. In general the parts of the andeclase rock that contain the least mafic and accessory minerals have a massive, interlocking, granular texture, which is medium- to coarse-grained. In many places there are coarse, rounded grains of feldspar and corundum, up to 5 cm in diameter. The scapolite rock is generally medium-grained equigranular; its texture, in contrast to the closely interlocking mosaic of minerals in the andeclase rock, is sugary, and the scapolite grains are rounded and not interlocking. Where there are quantities of dark minerals the andeclase and scapolite rocks tend to have a gneissic fabric, because of the parallel alignment of mica flakes and hornblende and pyroxene prisms and the tendency of the accessory minerals, particularly magnetite, to segregate into streaks and seams.

The nepheline-rich members of the complex have a gneissic fabric caused by the segregation of the principal constituents into nepheline-rich and nepheline-poor bands. The feldspar-rich bands range in thickness from less than a quarter of an inch up to 2 inches and are lenticular from 2 or 3 inches to 3 or 4 feet long. They are enclosed by nepheline-rich rock. The minerals of the nepheline gneiss form an interlocking, granular mosaic which is medium- to coarse-grained and is generally equigranular.

The orientation of the corundum grains and crystals relative to the planar elements of the metamorphic fabric of the andeclase and scapolite rocks could not be established in the field. In the nepheline gneiss the small corundum crystals may have any orientation from parallel to perpendicular to the gneissose planes, but the large crystals are either parallel or perpendicular to the gneissic banding. If the corundum crystals had formed before or during the development of the foliated fabric of the rock, all the corundum crystals should lie with their long axes in the plane of foliation. Probably the double orientation of the corundum crystals is due to post-deformational mimetic crystallization of this mineral; this seems the most reasonable explanation since the nepheline grains that enclose many of the corundum crystals appear to have formed after cessation of dynamic metamorphism. By this hypothesis the directions of growth of the corundum crystals were determined by two mutually perpendicular S-planes in the original rock, one of which is the present foliation. The other S-plane is not evident from megascopic examination of the rock, but may have been original cleavage or schistosity now obscured by the last period of dynamic metamorphism.

Chemical analyses of eight specimens of the scapolite-andeclase-nepheline gneiss complex are presented in Table 2. The analyses of the several specimens of each rock type were averaged for convenience in plotting on the Larsen variation diagram of Figure 4. Also plotted on this diagram is an average of the four analyses of the hybrid alkaline syenite of Table 4.

TABLE 2.—CHEMICAL ANALYSES AND CALCULATED MODES OF THE SCAPOLITE, ANDECLASE, AND NEPHELINE ROCKS

	1*	3*	4*	10*	11*	13*	18†	19*	A	B	C
SiO_2	51.54	49.72	53.87	47.37	45.62	44.72	52.29	47.72	45.90	51.71	50.0
Al_2O_3	24.13	29.43	27.58	24.83	26.63	24.34	25.67	31.25	25.30	27.05	28.46
FeO	3.82	5.52	1.92	3.16	2.64	4.99	1.87	2.62	3.60	3.75	2.25
Fe_2O_3	1.61	.60	1.37	2.60	3.49	5.76	2.35	.73	3.95	1.19	1.54
TiO_2	.18	.12	tr.	tr.	.12	.14	0.21	tr.	0.09	0.10	0.11
MnO	.15	.18	.08	.27	.18	.23	0.03	.14	0.23	0.14	0.08
CaO	8.96	5.86	6.26	11.88	11.02	9.16	1.28	1.06	10.70	7.03	1.17
MgO	.43	.63	.13	.33	.47	.49	tr.	.18	0.43	0.40	0.09
K_2O	.72	.85	1.68	.83	1.08	1.16	3.49	3.09	1.02	1.08	3.29
Na_2O	5.70	5.42	6.22	5.26	5.92	5.20	11.26	11.64	5.47	5.78	11.45
H_2O −105°C	.18	.19	.15	.12	.37	.42	0.09	Nil	0.30	0.17	0.05
H_2O +105°C	1.65	.74	.42	2.56	1.95	1.06	0.74	0.72	1.86	0.94	0.73
CO_2	.64	.46	.48	.63	.54	.04	tr.	tr.	0.05	0.05	tr.
P_2O_5	.13	Nil	.02	tr.	.12						
Total	99.84	99.72	100.16	99.74	100.15	98.73	99.92	100.11	99.14	99.92	100.05
Albite	49.2	47.2	58.0				34.0	26.2		51.5	30.1
Anorthite	31.7	26.4	28.1				2.0			28.7	1.0
Microcline							9.5	5.6			7.6
Nepheline							32.4	39.2			35.8
Corundum		7.5	2.5	0.2	1.7	0.3		5.1	0.7	3.3	2.6
Magnetite	2.4	0.9	1.9	3.7	5.3	8.4	3.5	0.9	5.8	1.7	2.2
Marialite				38.9	40.0	40.0			39.6		
Meionite				49.8	45.2	38.3			44.4		
Muscovite	5.7	3.2	4.0		4.8	5.6	16.5	12.8	3.5	4.3	14.7
Biotite		5.8	3.3	7.4	2.6	4.8		7.9	4.9	3.0	4.0
Spinel						2.6			0.9		
Ilmenite	0.7						0.5			0.2	0.3
Apatite	0.4				0.3				0.1	0.1	
Chlorite	8.4	8.0	1.1							5.9	
Carbonate	1.5	1.0	1.1				1.6	2.3		1.2	0.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	99.1

* Analyst, W. H. Herdsman.

† D. A. Moddle.

1. Andeclase rock from the south wall of cut 9, Klondike workings.
3. Andeclase rock from the south wall of cut 9, Craigmont workings.
4. Andeclase rock from the west end of cut 10, Craigmont workings.
10. Scapolite rock from the east end of cut 10, Craigmont workings.
11. Scapolite rock from the center of the east wall of cut 2, Craigmont workings.
13. Scapolite rock from the north end of the west wall of cut 2, Craigmont workings.
18. Nepheline gneiss from the farm yard of R. Gutz, lot 34, concession 5, Brundenell township.
19. Nepheline gneiss from the north wall of cut 2, Klondike workings.
A. Scapolite rock, average of analyses 10, 11, and 13.
B. Andeclase rock, average of analyses 1, 3, and 4.
C. Nepheline gneiss, average of analyses 18 and 19.

Any hypothesis for the origin of the scapolite-andeclase-nepheline gneiss complex must take into consideration the variations in the chemical compositions of the rocks from the oldest member of the sequence to the youngest. In the progressive development of the complex, there has been a general increase in silica, alumina, soda, and potassium and a decrease

in lime and iron oxides. The scapolite-andeclase-nepheline gneiss complex has a definite banded structure which bears some resemblance to the stratification in sedimentary rock sequences. In many exposures in the corundum workings the scapolite and andeclase rocks are intimately interbanded, and the individual bands range from less than an eighth of an inch up to a foot or more in thickness. The contacts between the bands are not sharp; instead, there is gradation in the proportion of feldspar and scapolite from plagioclase-rich to scapolite-rich layers. Individual bands and layers are not continuous along their strikes but pass gradually from one rock type into the other.

Other hybrid andeclase-scapolite facies consist of irregular masses ranging from 3 feet in diameter to the size of one grain of scapolite rock which generally grades into surrounding andeclase rock. In places massive coarse-grained andeclase rock contains lenslike inclusions of scapolite rock up to 6 inches thick and 2 or 3 feet long with sharp boundaries between the included and the enclosing rock.

At Reid Lake the scapolite, andeclase, and nepheline rocks are intercalated conformably in narrow bands which range from 1 to 18 inches in thickness. Contacts between bands may be sharp but are generally gradational over a narrow zone that seldom exceeds half an inch. In the nepheline gneiss, the proportions of plagioclase and nepheline range along the strike of the bands from more than 70 per cent nepheline to nearly 100 per cent plagioclase.

Elsewhere in the area, particularly along the York River in Carlow Township, the andeclase rock and the nepheline gneiss are conformably intercalated and grade into one another both along and across the strike of the banded structure.

These bands range in thickness from a few inches to several feet. The nepheline gneiss layers are usually discontinuous along the strike and are enclosed in massive andeclase rock.

Turner (1941) suggests that pseudostratification in metamorphic rocks may be caused by one or more of the following:

(1) Preservation of original sedimentary bedding
(2) *Lit-par-lit* injection of liquid magma
(3) Differential fusion of rocks during deep-seated ultrametamorphism
(4) Introduction of new material by magmatically derived pore solutions
(5) Metamorphic differentiation of rocks

The attitude of the banded corundum-bearing rock sequence is conformable with the attitude of the main metasedimentary rock sequences in the surrounding area; but since the two are separated by intervening granite and syenite masses and since original bedding in the metasediments was not recognized with any degree of certainty, there is no proof that the banding in the scapolite-andeclase-nepheline gneiss complex represents original sedimentary bedding. No relicts of sedimentary structures such as cross-bedding, grain gradation, or ripple marks were recognized. In many respects, the scapolite rock resembles calcareous skarn zones which are developed in Grenville metasediments in many parts of the subprovince, particularly in its high content of volatile-bearing minerals, its locally large segregations of magnetite, and the presence of garnet and pyroxene characteristic of such calcareous skarns. Accordingly, the banded structure of the corundum-bearing complex probably represents, in part at least, original layering in sedimentary rocks.

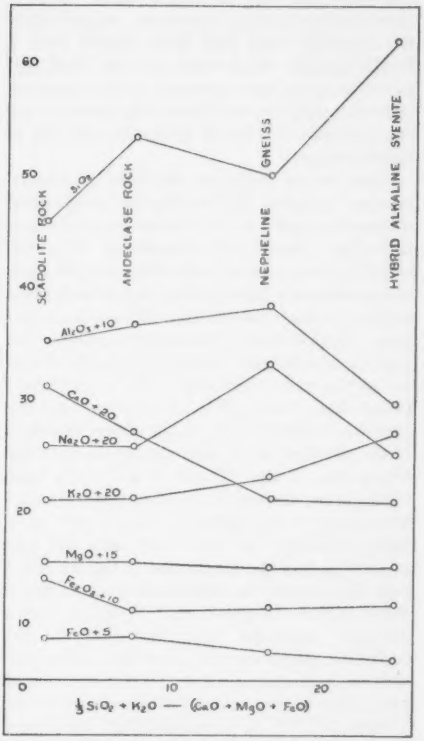

FIGURE 4.—LARSEN VARIATION DIAGRAM OF SCAPOLITE ROCK, ANDECLASE ROCK, NEPHELINE GNEISS AND HYBRID ALKALINE SYENITE

No positive evidence of the intrusion of the liquid magma was seen in any part of the corundum-bearing complex. However, the plagioclase-scapolite relations in the hybrid zones and the relatively large, irregular inclusions of scapolite rock in the massive phases of the andeclase rock, as well as their intimate interbanding in many exposures, suggests that the andeclase rock may have formed from a liquid magma which was injected into and partially assimilated portions of the scapolite rock. Accordingly, the banded structure of the complex may be due to *lit-par-lit* injection of liquid magma.

There is no evidence that the corundum-bearing complex has undergone deep-seated ultrametamorphism. The metasedimentary amphibolites which are interbanded with the complex, have mineral assemblages appropriate to a moderately high grade of dynamo-thermal regional metamorphism. Had these rocks undergone deep-seated ultrametamorphism the mineral assemblage in the amphibolite should indicate a more advanced grade of metamorphism than it does. It must be noted that the chemical compositions of the three members of the complex differ, although there are some similarities. These differences may have been effected by metasomatic alterations through the agency of magmatically derived pore solutions. Evidence cited previously indicates that at least part of the plagioclase in the andeclase rock has formed by replacement of scapolite. Some evidence suggests that nepheline and a younger generation of plagioclase in the nepheline gneiss formed later than, and possibly by replacement of, an older generation of plagioclase similar to that in the andeclase rock.

Hewitt (1953, p. 96) emphasized the importance of metamorphic differentiation during periods of dynamo-thermal regional metamorphism, in the production of the marked internal foliation in the nepheline gneisses. He pointed out that in many exposures these rocks contain considerable quantities of volatile-bearing minerals such as fluorite and suggests that in advanced stages of metamorphism these phases of the nepheline, by a self-fluxing process, may be able to migrate to new positions forming (1) those portions of the nepheline gneisses which are rich in feldspathoids and (2) the coarse-grained, irregular, cross-cutting nepheline pegmatites. This mobilized material may even migrate into and replace adjacent metasedimentary rocks.

In summation, the banded structure of the corundum-bearing scapolite-andeclase-nepheline gneiss complex is probably original sedimentary bedding, which may have been modified by sill-like injection of liquid magma, introduction of new material by magmatically derived pore solutions, or metamorphic differentiation.

The field and petrographic evidence suggests the following sequence of events:

(1) The development of the scapolite rock by the alteration and replacement of calcareous sediments: this process would involve the addition of silica, soda, and alumina and the extraction of lime, magnesia, and carbon dioxide.

(2) The formation of the andeclase rock, at least partly at the expense of the scapolite rock: it is possible that in those portions of the andeclase rock adjacent to the scapolite facies, plagioclase formed by metasomatic alteration of scapolite. Accordingly, it is possible that all the andeclase rock developed by metasomatic alteration of scapolite rock or of other interbanded metasedimentary facies. However, it is equally possible that the andeclase rock crystallized from a liquid magma which was injected as sill-like masses into and partially assimilated portions of the scapolite rock.

(3) The development of the nepheline rock, possibly at the expense of andeclase rock: this process would involve the addition of soda, alumina, and minor potassium and the extraction of lime, iron, magnesia, and a little silica from the andeclase rock.

Granite-Syenite Gneiss Complex

The most important member of the granite-syenite gneiss complex is the hybrid alkaline syenite. Granite gneiss and migmatite underlie the banded corundum-bearing and syenitic rock sequence exposed on the south slope of Robillard Mountain and appear to overlie the sequence at depth but were not seen in contact with any member of the scapolite-andeclase-nepheline gneiss complex. The granite gneiss grades, by progressive decrease in its content of quartz, into the hybrid alkaline syenite.

The mineral compositions of members of the granite-syenite gneiss complex estimated from the field and thin-section investigations are presented in Table 3.

The reddish-pink to sandy-buff hybrid alkaline syenite masses enclose relict bands and lenses of the older rock types, and dikelets, stringers, and patches of syenite irregularly cut and permeate them. The cross-cutting dikelets and stringers are nondilational types, that

is, where they cut across gneissic structures in the earlier rocks at acute angles, there is no apparent offsetting of the gneissic bands, and the dikelets and stringers do not have matching walls.

rocks. The plagioclase in the syenites has two compositional ranges; one corresponds to that of the plagioclase in the andeclase rock and the older generation of feldspar in the nepheline gneiss, and the other corresponds to that of the

TABLE 3.—ESTIMATED MINERAL COMPOSITIONS OF THE GRANITE AND SYENITE GNEISSES

Per Cent Composition

	Hybrid alkaline syenites		Quartz-arfvedsonite syenite		Granite gneiss		Granite-syenite pegmatites	
	Range	Average	Range	Average	Range	Average	Range	Average
Corundum	....	....	....	....	....	....	....	....
Plagioclase	93–2	46.0	36–71	57.0	46–50	48.0	....	....
Microcline	93–0	47.0	15–45	27.0	25–23	24.0	....	....
Magnetite	13–0	3.0	2–1	1.3	tr.	tr.	....	....
Biotite	6–0	1.0	2–1	1.0	tr.	tr.	....	....
Muscovite	4–0	1.0	tr.	tr.	tr.	tr.	....	....
Pyroxene	27–0	1.0	11–1	5.0	....	....	....	....
Hornblende	3–0	tr.	....	....	tr.	tr.	....	....
Arfvedsonite	....	....	4–0	2.0	....	....	....	....
Quartz	....	....	17–0	6.0	29–25	27.0	....	....
Apatite	1–0	tr.	1–0	1.0	tr.	tr.	....	....
Sphene	6–0	tr.	1–0	1.0	tr.	tr.	....	....
Zircon	....	tr.	....	tr.	....	tr.	....	....
Pyrite	....	....	....	....	....	....	....	....
Sec. white mica	....	tr.	....	tr.	....	tr.	....	....
Carbonate	3–0	tr.	....	tr.	....	tr.	....	....
Chlorite	2–0	tr.	....	tr.	....	tr.	....	....

PLAGIOCLASE COMPOSITION

	Average	Number	Average	Number	Average	Number	Average	Number
An_{20} to An_{26}	An_{25}	8	....	....	....	....	....	....
An_{27} to An_{33}	An_{29}	49	An_{31}	10	An_{28}	2	An_{30}	3
An_{34} to An_{37}	An_{34}	4	An_{34}	1	....	....	....	....
An_4 to An_{14}	An_{10}	4	....	....	....	....	....	....

The hybrid alkaline syenite complex is extremely and erratically variable in mineral composition and in fabric. The characteristic feature of its mineral composition is the presence of microcline feldspar. The relative proportions of plagioclase and the potassium feldspar may range from more than 90 per cent plagioclase with a few per cent microcline to more than 90 per cent microcline with only traces of plagioclase. Generally those portions of the complex having a more pronounced pinkish color are richer in potassium feldspar.

Anhedral plagioclase grains in the syenite have interlocking contacts with their neighbors. Many grains show strain shadows and slightly bent twin lamellae in the same manner as does the plagioclase in the andeclase and nepheline

younger generation of plagioclase in the nepheline rock. Syenite containing plagioclase of the latter composition is found only near bands or patches of the nepheline gneiss. In the syenite, however, plagioclase of both types is commonly altered to secondary white mica and a little carbonate, and many grains are dusty with minute dark inclusions of unknown composition. This alteration is generally erratically developed even in a single thin section, is generally mild, and is nowhere intense. Many plagioclase grains in the syenite have partial, intermittent to complete rims of albitic feldspar. The sodic rims, generally thin, are fresh and clear and are found only in those portions of the rock where at least a moderate amount of microcline is present.

In the hybrid alkaline syenite complex plagioclase and microcline form perthitic intergrowths of a kind which Alling (1938, p. 142) suggests is caused by replacement of one mineral by the other; here plagioclase has been replaced by microcline.

The mafic minerals have an erratic distribution in the hybrid syenite; in a few narrow bands, lenses, and irregular, elongate zones, one or more may be relatively abundant, but throughout most of the complex the mafic minerals are minor or absent. The pyroxene and hornblende in the syenite are identical in appearance and optical properties with the pyroxene and hornblende found in the andeclase and scapolite rocks. Magnetite is more evenly distributed in the syenite, though in many phases it may be absent. Many of the small to medium-sized anhedral grains of magnetite have partial to complete halos of muscovite.

Corundum is absent from most of the hybrid alkaline syenite complex. In places minor corundum occurs in the syenite adjacent to hybrid relicts of corundum-bearing facies of the earlier rock types, but these corundum syenite zones are generally less than a few inches thick. According to Adams and Barlow (1908 p. 70–71):

> "The rock, which contains the largest and most abundant crystals and masses of corundum at Craigmont, and thus the richest ore of this mineral, is the corundum-syenite-pegmatite, which occurs in the form of dikes or veins, varying from six to eighteen feet in width. These dikes intersect the medium-grained or normal type of red syenite just described, which also contains corundum although in less abundance and in smaller individuals. They are made up almost wholly of a deep flesh-red to very pale salmon-pink feldspar, which, in thin sections under the microscope, is seen to be an irregular intergrowth of orthoclase and albite, the former feldspar being the more abundant. Associated with this microperthite are corundum, biotite, scapolite, calcite, magnetite, heamatite (micaceous iron ore, molybdenite, pyrrhotite, chalcopyrite, chrysoberyl, spinel, and quartz. All these, with the exception of the first mentioned, occur as accessory constituents in certain places and are usually present in small amount. Although quartz and corundum are commonly supposed to be mutually exclusive, specimens have been found in which small quantities of both of these minerals are present."

No cross-cutting dikes or veins of corundum syenite pegmatite were seen by the writer in the corundum workings. Possibly these may have been mined out, but it is more probable that the bodies referred to by Adams and Barlow were similar to certain lenses and irregular masses of coarse-grained, inequigranular, pegmatitic corundum syenite which are irregularly distributed through the hybrid alkaline syenite complex but are most prevalent near the relict bands of the earlier rock types. These pegmatitic phases range from deep reddish pink to light sandy buff and consist predominantly of coarse grains and crystals of feldspar and corundum, up to 4 inches in diameter, set in an aplitic groundmass of feldspar. Biotite and magnetite are present in minor amounts in a few places. No calcite, molybdenite, pyrrhotite, chalcopyrite, or quartz was observed in these pegmatitic corundum-bearing phases, and except for the presence of corundum these are indistinguishable from the coarse-grained, inequigranular phases of the hybrid alkaline syenite complex. In a sense both of these coarse-grained phases cut the syenite; they occur in irregular, elongate masses, roughly parallel to the banded structure of the complex, but are not banded themselves. However, they do show textural, mineralogical, and structural gradation into the enclosing syenite. The writer believes that Adams and Barlow confused the coarse-grained phases of the syenite complex with intrusive, cross-cutting dikes of granite and syenite pegmatite. The latter are generally characterized by a relative abundance of hornblende, but where this mineral is absent the two facies are similar in appearance and mineral composition, except for small amounts of quartz, calcite, and sulfides in the pegmatites. Where such pegmatite dikelets cut the coarse-grained corundum-rich phases of the syenite, one can get hand specimens along their contacts that contain small amounts of both corundum and quartz.

The contact zones between the hybrid alkaline syenite and the scapolite-andeclase-nepheline gneiss complex generally contain more corundum than the unaltered older rocks, and this mineral is more evenly distributed through these zones than it is in the older complex. Considerably altered inclusions of the older rocks in the syenite are usually richer in corundum than the less altered inclusions.

The fabric of the hybrid alkaline syenite complex is as variable as its mineral composition. Textures range from medium-grained, equigranular aplitic to inequigranular, coarse-grained, with large, rounded grains of feldspar and mafic minerals up to 1 inch in diameter enclosed in a medium- to coarse-grained feldspar groundmass. In places coarse-grained, almost pegmatitic, phases are developed with abundant coarse, rounded grains of feldspar, up to 3–4 inches in diameter, in a subordinate

TABLE 4.—CHEMICAL ANALYSES AND CALCULATED MODES OF HYBRID ALKALINE SYENITE

Analyst, W. H. Herdsman

	2	8	9	23	24	25	26	A
SiO_2	59.07	58.12	64.82	61.36	63.42	64.37	62.22	61.93
Al_2O_3	20.94	19.43	19.73	20.64	19.33	19.41	19.78	19.78
FeO	2.64	3.99	1.38	0.87	0.86	0.80	0.68	1.78
Fe_2O_3	2.93	4.98	1.44	1.16	0.58	1.10	1.07	1.79
TiO_2	0.13	0.26	tr.	0.04	nil.	0.15	0.08	0.07
MnO	0.16	0.06	0.07	0.06	tr.	0.01	0.02	0.05
CaO	1.92	1.58	0.78	0.73	0.72	0.31	1.50	0.95
MgO	0.14	0.22	tr.	0.62	0.29	0.06	0.60	0.28
K_2O	2.40	4.31	6.52	7.58	9.70	6.77	4.66	7.03
Na_2O	8.96	6.09	5.16	5.44	4.05	5.73	7.52	5.19
H_2O − 105°C	0.20	0.18	0.17	0.28	0.20	0.10	0.05	0.22
H_2O + 105°C	0.32	0.49	0.09	0.77	0.46	0.30	0.67	0.45
CO_2	0.28	tr.	tr.	0.32	0.35	0.11	1.07	0.17
P_2O_5	tr.	0.07	nil.	tr.	nil.	tr.	nil.	0.02
	100.09	99.78	100.16	99.87	99.96	99.25	99.92	99.71
CALCULATED MODES								
Albite	60.3	47.6	40.9	37.2	26.2	42.5	58.7	38.0
Anorthite	12.0	7.2	3.9	1.7	1.1	0.8	0.6	3.5
Microcline	16.7	28.0	51.7	50.4	65.6	47.8	26.1	48.9
Corundum	....	....	....	1.5	....	....	....	0.4
Magnetite	4.2	7.2	2.1	1.9	0.9	1.6	1.6	3.0
Muscovite	2.4	4.0	....	4.8	4.0	5.6	6.4	3.2
Biotite	....	5.1	1.4	....	....	1.5	4.1	1.6
Ilmenite	0.3	0.6	....	....	....	....	....	0.1
Apatite	....	0.3	....	....	....	....	....	0.1
Chlorite	3.4	....	....	1.8	1.3	....	....	0.8
Carbonate	0.7	....	....	0.7	0.9	0.2	2.5	0.4
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

2. From the south wall of cut 9, Craigmont workings.
8. From the east wall of cut 1, Craigmont workings.
9. From the north end of cut 2, Craigmont workings.
23, 24. From the center of the east wall of cut 1, Klondike workings.
25, 26. From the south end of the west wall of cut 6, Klondike workings.
A. Average of analyses 8, 9, 23, and 24.

groundmass of medium-grained feldspar. Where present the mafic rocks tend to be segregated into bands, lenses, and seams and impart a gneissic fabric to those sections of the complex. All gradations occur from one textural and mineralogical phase of the complex to any of the others.

The hybrid alkaline syenite complex has a definite banded structure because of (1) parallel alignment of prisms and flakes of mafic minerals and their tendency to segregate into rude layers and bands; (2) bands, lenses, and elongate patches of earlier rocks enclosed in the complex roughly parallel the foliation planes of its gneissic phases; (3) The different shades and colors of the hybrid alkaline syenite, which seem to reflect variations in the relative proportions of potassium feldspar and plagioclase in the rock, tend to occur in thin bands, lenses, and irregular elongate patches parallel to the gneissic structure and to alignment of inclusions.

The banded structure of the syenite complex is conformable with that of the scapolite-ande-

clase-nepheline gneiss complex and may be inherited from the older rocks. Accordingly, it appears that the syenite complex was not emplaced by the forceful intrusion of a magma with consequent breaking and thrusting aside of earlier rocks. Chemical analyses of seven specimens of the hybrid alkaline syenite complex are presented in Table 4. Analyses 8, 9, 23, and 24 were made on specimens which represent a close approximation to the average mineral composition of the syenite as shown in Table 3. The average of the four analyses plotted on the Larsen variation diagram (Fig. 4) indicates that the syenite contains considerably more silica and potassium and considerably less alumina than any of the older rocks. The syenite contains about the same amount of lime as the nepheline rock but considerably less soda, whereas it contains about the same amount of soda as the andeclase and scapolite rocks but considerably less lime.

Contacts of the hybrid alkaline syenite complex with the enclosed bands and lenses of the earlier rocks are generally gradational; relatively few sharp and no chilled contacts were seen. The nature of the mineralogical and chemical changes across these gradational contact zones illustrates the processes by which the alkaline syenite complex has replaced the pre-existing rocks.

Contacts between the amphibolite and the syenite generally appear sharp in the hand specimen. In thin sections, however, the mineral grains of both rock types are seen to interlock across a rather indefinite boundary zone. Perthite of the replacement type is in many places developed in the amphibolite adjacent to such contacts, and the syenite generally contains at least a minor quantity of mafic constituents along the boundaries.

Contacts between the scapolite rock and the alkaline syenite are commonly rather sharp. Thin-section examination of these sharp contacts shows that in many places microcline directly replaces scapolite along them; in other places, where microcline is not abundant in the adjacent syenite, the scapolite has been variably altered in narrow zones along the contacts to fine-grained mixtures of secondary white mica with minor chlorite.

The gradational contact zones between the syenite and the andeclase rock may range from a few inches to several feet in width. Across such a contact from fresh unaltered andeclase rock toward the hybrid alkaline syenite the first change noted is the development in the plagioclase of minute dark inclusions of unknown composition accompanied by fine-grained secondary white mica concentrated along grain boundaries and cracks and cleavage planes in the feldspar. Farther across the contact this alteration of the plagioclase becomes progressively more intense, and the dark inclusions are spread more evenly as a dirty, dusty haze over the surfaces of the individual grains. Thin films of reddish material, resembling iron oxides, appear along feldspar cleavage planes; the flakes of secondary white mica increase in size sufficiently to be identified as muscovite, in places having the composition of phengite. Farther across the contact, microcline increases progressively, having replaced the altered plagioclase. Sodic rims on many plagioclase grains accompanied the development of the microcline. Microcline has also replaced ragged anhedral laths of muscovite, isolated relicts of which are in optical and crystallographic continuity with one another and are enclosed in clear, fresh grains of the potassium feldspar. With progressive increase in the quantity of microcline the contact zones grade into the hybrid alkaline syenite. The mafic minerals of the andeclase rock, for the most part, have been little affected by the replacement processes and persist through the contact zones in a relatively clear and fresh condition.

Corundum appears to be more common and somewhat more abundant in these contact zones than in the andeclase rock; its manner of occurrence here is similar to that in the unaltered andeclase rock.

Paralleling the mineralogical variations, the colors range from the light greyish white of the andeclase rock through shades of buff grey, buff, and pink buff to deeper shades of pink in the microcline-rich sections of the syenite complex. Changes in fabric are slight in the transitional zones between the syenite and the andeclase rock. Gneissic phases of the latter grade into foliated portions of the hybrid complex; coarse-grained inequigranular phases grade into their counterparts in the syenite. Transitions from all mineralogical and textural phases of the andeclase rock into the hybrid alkaline syenite complex are represented. Thus the banded structure of the syenite complex is at least partly inherited from earlier rocks.

Contacts between hybrid andeclase-scapolite rock facies and the syenite complex are similar to those described above as far as the andeclase rock is concerned. The included masses, particles, and grains of scapolite, however, were not so readily replaced by microcline as was the plagioclase. The scapolite generally was first

altered to a fine-grained mixture of secondary white mica with minor chlorite, and these pseudomorphs then were replaced by microcline. The larger masses of scapolite in many places persist in an unaltered form, though the andeclase rock enclosing them has been transformed into alkaline syenite.

The hybrid altered phases of the andeclase rock in the contact zones with the syenite and the hybrid altered inclusions of andeclase rock in the syenite complex contain more corundum than the unaltered phases. The corundum has a much more general distribution in the altered than in the original rock. Not uncommonly corundum is present in appreciable amounts in altered andeclase rock, whereas adjacent unaltered portions of this facies have no corundum. The corundum in these altered facies is no different in color, shape, or general appearance than the corundum in the unaltered rock. It occurs in large to small, euhedral to anhedral grains, most of which have the usual muscovite halos. However, muscovite pseudomorphs after corundum are much more common in these zones than in the unaltered andeclase rock. There is no textural evidence in the altered zones to indicate that corundum developed at the expense of the other minerals. It has mutual contacts with the plagioclase and microcline grains where the muscovite selvages are absent.

Since it appears that at least a part of the hybrid alkaline syenite complex formed by transformation of the andeclase rock, *in situ*, into syenite, knowledge of the chemical changes in the transformation may throw some light on the origin of the corundum in the transitional zones. The information summarized on the Larsen variation diagram (Fig. 4) indicates that in the transformation silica and potassium have been added, lime and alumina have been subtracted, and soda, magnesia, and iron oxides remained roughly constant.

Several chemical analyses were made of specimens of the intermediate phases. Specimen 3 in Table 5 was buff-grey syenite taken 10 feet away from fresh unaltered andeclase rock (Table 5, specimen 2). The syenite-andeclase rock contact is imperceptible. These analyses shown diagrammatically in the Larsen variation diagram (Fig. 5) indicate that in the transformation of the andeclase rock into syenite, silica and soda were added; alumina, lime, magnesia, and iron oxides were subtracted, and potassium remained constant.

The differences in the mineral compositions of the samples are due partly to different original compositions of the andeclase rock which was transformed into syenite and the unaltered andeclase rock analyzed for comparison. For instance, the composition of the plagioclase in sample 3 is An_{34}, whereas the composition of the original plagioclase in sample 2 is An_{26}; the composition of the latter was modified considerably by the development of rims of albitic feldspar. Thus the gain in albite and loss in anorthite molecules when comparing samples 2 and 3 were due partly to differences in composition of the original plagioclase and partly to the development of secondary albite in sample 2 at the expense of original feldspar. Also, thin sections show that biotite was rarely affected during the transformation of andeclase rock to syenite; therefore the difference in biotite content of the two samples must reflect its original distribution in the andeclase rock.

All three members of the scapolite-andeclase-nepheline gneiss complex are nonhomogeneous in mineral composition. Therefore, quantitative estimates of the amounts and kinds of material added and subtracted from these facies during replacement cannot be made, since it is impossible to be sure that the original mineral and chemical compositions of altered phases of these rocks corresponded to those of the unaltered phases analyzed for comparison.

Specimens 12 and 14 of Table 5 were slightly altered hybrid andeclase-scapolite rocks that grade across their strikes into hybrid alkaline syenite (Table 5, specimen 8).

The diagrams (Figs. 6, 7) of these analyses indicate that, in the transformation of the hybrid andeclase-scapolite facies to syenite, silica, potassium, and minor amounts of iron oxides were added, lime and alumina were subtracted, and soda and magnesia remained about constant.

Specimens 4, 5, 6, and 7 of Table 5 are a series taken at intervals across a gradational corundum-rich contact zone between fresh andeclase-corundum rock and hybrid alkaline syenite. These analyses are plotted on a Larsen variation diagram in Figure 8.

It is evident that in the course of the alteration of the andeclase rock the transitional zone between this facies and the syenite was enriched in alumina and potassium, whereas lime, soda, and combined iron oxides were removed, and silica and magnesia remained roughly constant.

Composition of the original plagioclase in specimen 4 is An_{33}, in specimen 5 An_{31}, and in specimens 6 and 7 An_{27}, as determined by optical methods. In samples 5, 6, and 7 the compositions of the original plagioclase were altered by the development of considerable secondary

TABLE 5.—CHEMICAL ANALYSES AND CALCULATED MODES OF TRANSITIONAL PHASES BETWEEN ANDECLASE ROCK AND HYBRID ALKALINE SYENITE

Analyst, W. H. Herdsman

	2	3	12	14	8	4	5	6	7
SiO_2	59.07	49.72	51.34	53.28	58.12	53.87	53.04	53.44	52.32
Al_2O_3	20.94	29.43	24.96	23.56	19.43	27.58	27.46	28.16	33.28
FeO	2.64	5.52	3.52	2.74	3.99	1.92	2.62	2.71	1.04
Fe_2O_3	2.93	0.60	4.79	3.94	4.98	1.37	2.58	3.48	0.73
TiO_2	0.13	0.12	0.08	0.09	0.26	tr.	tr.	0.12	nil.
MnO	0.16	0.18	0.19	0.12	0.06	0.08	0.12	0.13	tr.
CaO	1.92	5.86	4.62	6.53	1.58	6.26	3.23	2.12	2.03
MgO	0.14	0.63	0.43	0.38	0.22	0.13	0.46	0.23	0.38
K_2O	2.40	0.85	1.04	0.77	4.31	1.68	1.51	1.05	3.74
Na_2O	8.96	5.42	7.16	5.65	6.09	6.22	6.98	6.96	5.38
H_2O −105°C	0.20	0.19	0.32	0.25	0.18	0.15	0.30	0.39	nil.
H_2O +105°C	0.32	0.74	0.48	2.02	0.49	0.42	0.86	0.48	0.57
CO_2	0.28	0.46	0.82	0.26	tr.	0.48	0.62	0.43	0.44
P_2O_5	tr.	nil.	tr.	0.02	0.07	0.02	0.02	0.05	0.03
	100.09	99.72	99.84	99.61	99.78	100.16	99.80	99.75	99.84
Albite	60.3	47.2	41.9	42.4	47.6	58.0	60.3	58.7	45.6
Anorthite	12.0	26.4	10.3	20.0	7.2	28.1	13.1	7.8	7.5
Microcline	16.7	....	....	....	28.0	....	....	8.3	18.4
Corundum	....	7.5	3.8	2.2	....	2.5	7.3	8.1	13.7
Magnetite	4.2	0.9	7.0	5.6	7.2	1.9	3.5	5.1	0.9
Marialite	....	....	15.2	11.0	....	....	....	....	....
Meionite	....	....	8.7	10.6	....	....	....	....	....
Muscovite	2.4	3.2	8.8	4.0	4.0	4.0	7.2	7.2	9.6
Biotite	....	5.8	....	....	5.1	3.3	7.2	2.2	3.3
Ilmenite	....	....	....	....	0.6	....	....	....	....
Apatite	....	....	....	....	0.3	....	....	0.2	....
Chlorite	3.4	8.0	3.7	....	....	1.1	....	1.4	....
Carbonate	0.7	1.0	0.9	....	....	1.1	1.4	1.0	1.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

2. Hybrid alkaline syenite from the south wall of cut 9, Craigmont workings; taken directly on the strike of sample 3, 10 feet away.

3. Andeclase rock.

12. Hybrid andeclase-scapolite rock (slightly altered) from the center of the east wall of cut 2, Craigmont workings.

14. Hybrid andeclase-scapolite rock (somewhat altered) from the north end of the west wall of cut 2, Craigmont workings.

8. Hybrid alkaline syenite from the east wall of cut 1, Craigmont workings.

4. Andeclase rock from the west end of cut 10, Craigmont workings.

5. Andeclase rock (slightly altered) from the center wall of cut 9, Craigmont workings; grades into 4.

6. Hybrid buff corundum syenite taken on the strike, 3 feet away from sample 5; contact imperceptible.

7. Hybrid pink corundum syenite taken on the strike, 2 feet away from sample 6; contact imperceptible.

white mica, and in samples 6 and 7 they were altered by the development of albitic rims around many grains.

The chemical evidence shows clearly that, although the transformation of andeclase rock to syenite ultimately involves the subtraction of alumina from the former facies, portions of the transitional zones may be enriched in alumina during the transformation. The origin of the corundum in the gradational zones

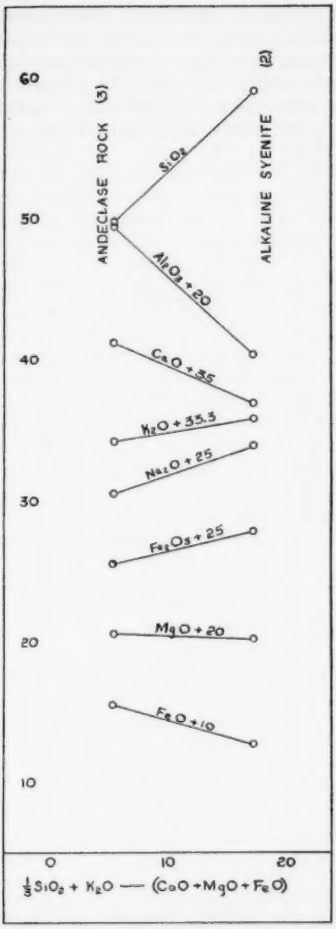

FIGURE 5.—LARSEN VARIATION DIAGRAM OF ANDECLASE ROCK AND ALKALINE SYENITE

between the andeclase rock and syenite is probably largely due to the recrystallization of the alumina released by the alteration of the former facies. The following equations show the reactions that appear to have taken place in these zones:

$$K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O \rightarrow \underset{\text{Muscovite}}{K_2O \cdot Al_2O_3 \cdot 6SiO_2} + \underset{\text{Microcline}}{2H_2O + 2Al_2O_3} \quad (1)$$

$$\underset{\text{Corundum}}{}$$

$$7(Na_2O \cdot Al_2O_3 \cdot 6SiO_2) \cdot 6(CaO \cdot Al_2O_3 \cdot 2SiO_2)$$

$$\underset{\text{Plagioclase (An}_{30}\text{)}}{} + 10K_2O + 6SiO_2$$

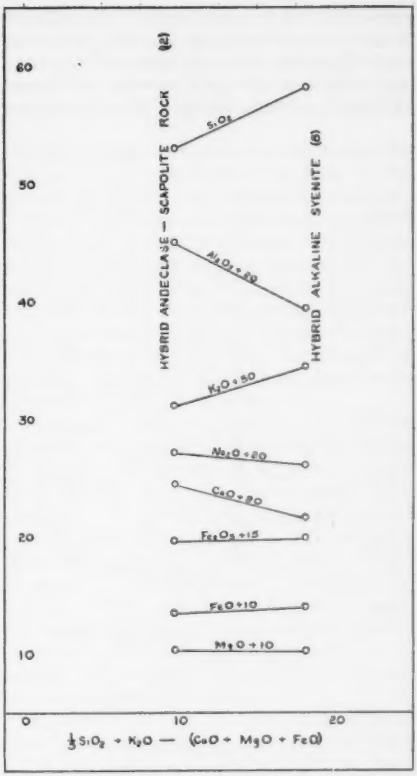

FIGURE 6.—LARSEN VARIATION DIAGRAM OF HYBRID ANDECLASE-SCAPOLITE ROCK AND HYBRID ALKALINE SYENITE

$$\rightarrow \underset{\text{Microcline}}{10(K_2O \cdot Al_2O_3 \cdot 6SiO_2)} + 6CaO \quad (2)$$

$$+ \underset{\text{Corundum}}{7Na_2O + 3Al_2O_3}$$

Contacts between the nepheline gneiss and the hybrid alkaline syenite complex are gradational; they range in width from a few inches to 20 feet or more. Grading from unaltered nepheline gneiss toward syenite, the first change is the alteration of the clear, glassy nepheline to dull chalky-white to pinkish hydronephelite. The latter is a fine-grained aggregate of zeolites and secondary white mica, which is first developed along grain boundaries and cracks in the nepheline grains, then spreads erratically through them until all the original mineral is replaced. The plagioclase grains remain generally fresh and clear except that in some places

where they are in contact with hydronephelite narrow zones of radiating, sheaflike clusters of tiny clinozoisite grains surround and alter them and form a border zone between the altered nepheline and the feldspar. The clinozoisite

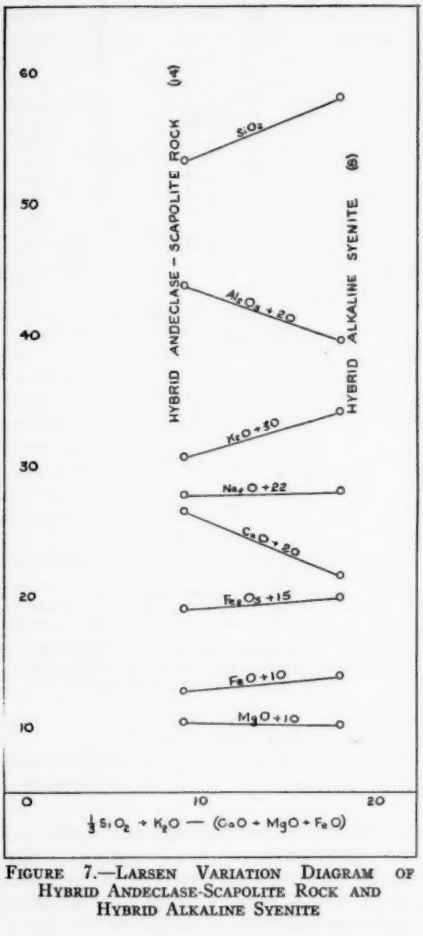

FIGURE 7.—LARSEN VARIATION DIAGRAM OF HYBRID ANDECLASE-SCAPOLITE ROCK AND HYBRID ALKALINE SYENITE

border zones have sharp contacts with adjacent hydronephelite but ragged, irregular contacts with the interiors of the plagioclase grains. The clinozoisite is minor; it is absent in many sections of the rocks and never abundant anywhere in them.

Farther across the contacts the hydronephelite zone grades into a hybrid buff syenitic rock containing considerable corundum and muscovite. These zones are characterized by microcline, which developed at the expense of plagioclase and also by replacement of the hydronephelite. The latter phenomenon shows clear, fresh microcline penetrating, enclosing, and progressively replacing the dusty fine-

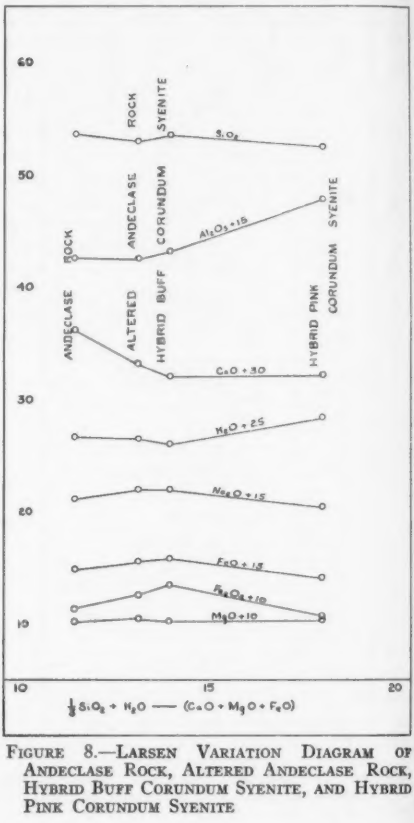

FIGURE 8.—LARSEN VARIATION DIAGRAM OF ANDECLASE ROCK, ALTERED ANDECLASE ROCK, HYBRID BUFF CORUNDUM SYENITE, AND HYBRID PINK CORUNDUM SYENITE

grained aggregate of zeolites and secondary white mica. Gieseckite, a greenish mineral aggregate similar to hydronephelite but containing fine-grained chlorite, developed in many places in the hybrid buff syenitic zones, particularly near minor shears and faults. The surfaces of the joints in the nepheline gneiss are coated with a thin layer of hydronephelite overlain by a layer of gieseckite; the zone of alteration ranges from less than a quarter of an inch to 1 inch in thickness. The nepheline gneiss adjacent to faults and shears has been similarly altered; the narrower cracks are

characterized by a zone of alteration up to 1 inch wide on both sides; the wider shears have gouge and alteration zones which are up to 1 foot wide. In places these wider shears are filled with soft, crumbly, schistose masses of biotite and pinkish feldspar. In other places, the nepheline gneiss adjacent to the shears has been altered to hybrid biotite-rich syenite. Along one narrower fault a zone, up to 2 inches wide, of bluish scapolite is developed between the fault proper and the hydronephelite zone adjacent to the nepheline gneiss.

These relationships suggest that the faults and shears developed during and after the formation of the syenite; had they formed prior to the emplacement of the syenite, the faults and shears should have been filled and welded by the metasomatizing processes. The joints probably formed after the development of the syenite, for, if they had existed before, the syenite would have developed along these joint planes.

Accordingly, there appear to have been two periods of alteration of nepheline gneiss to hydronephelite and gieseckite; the first was an initial stage in the transformation of the nepheline rock to syenite. Hydronephelite zones occur between the two facies, regardless of whether or not there are near-by shears, faults, or joints. These hydronephelite zones grade imperceptibly into the syenite, as the microcline of the latter progressively increases at the expense of the hydronephelite. This progressive alteration of nepheline to hydronephelite to microcline is unusual. The transformation of nepheline to hydronephelite indicates a hydrous environment and low temperatures, whereas the transformation of hydronephelite to microcline indicates higher-temperature dehydrating conditions. These facts may indicate a considerable time interval between the first and second mineral transformations, although the field relationships show them to be related phases of a single rock-forming process. The second period of the development of hydronephelite and gieseckite in the nepheline gneiss may be attributed to metasomatic alteration of this facies along the joint planes by solutions emanating from the late intrusive granite and syenite pegmatites which cut all other rocks in the corundum workings.

Corundum appears to be more abundant in the hybrid buff phases of the transition zones than in the nepheline gneiss.

Two generations of corundum may be present in these zones: an early generation present in the original nepheline gneiss as long, narrow, euhedral crystals, now extensively replaced by muscovite, and a later generation occurring in more equidimensional grains, some of which have no mica halos. This later corundum does not show the preferred orientation of the earlier grains.

Farther across the contact zones toward the microcline-rich reddish-pink portions of the hybrid alkaline syenite complex, muscovite developed at the expense of the enclosed corundum grains, and microcline replaced plagioclase, hydronephelite, gieseckite, and muscovite. The result is a microcline-rich syenite with subordinate amounts of plagioclase, a little muscovite, and minor accessory minerals. All stages in the gradual transition from nepheline gneiss to hybrid alkaline syenite may be traced in the field and under the microscope.

Chemical analyses of several transitional phases in the transformation of nepheline gneiss to syenite are presented in Table 6. The contacts between the rock types are gradational. Sample 16 is hybrid buff corundum syenite taken directly on the strike of and 10 feet away from hydronephelite-corundum gneiss (Table 6, sample 17). These analyses are plotted on the Larsen variation diagram of Figure 9. In the transformation of nepheline gneiss into syenite, silica was added, alumina, soda, and lime removed, and potassium, iron oxides, and magnesia remained about constant.

Specimen 25 (Table 6) is a pink alkaline syenite taken 3 feet above and grading across strike into hybrid buff syenite (Table 6, specimen 26); this rock grades into nepheline gneiss (Table 6, specimen 27) 3 feet below the location of sample 6. It is evident from the Larsen variation diagram (Fig. 10) that in the transformation of the nepheline gneiss to pink alkaline syenite, silica and potassium were added, and soda, alumina, lime, and minor amounts of iron oxides and magnesia were removed.

Specimens 20, 21, 22, 23 and 24 of Table 6 represent various phases in the transformation of nepheline gneiss to pink alkaline syenite across a contact zone about 8 feet wide.

It is evident from Figure 11 that in the transformation silica and potassium were added, and alumina, lime, soda, iron oxides, and minor amounts of magnesia were extracted.

Differences in the mineral compositions of the samples taken across these contact zones probably reflect, in part, variations in the composition of the original rock. Otherwise the differences are due to the development of the new minerals of the syenite, principally microcline,

TABLE 6.—CHEMICAL ANALYSES AND CALCULATED MODES OF TRANSITIONAL PHASES BETWEEN NEPHELINE GNEISS AND HYBRID ALKALINE SYENITE

	16*	17*	18*	25*	26*	27*	20†	21†	22†	23†	24†
SiO_2	57.00	54.18	52.29	64.37	62.22	45.90	45.34	44.75	48.78	61.36	63.42
Al_2O_3	24.91	24.21	25.67	19.41	19.78	29.79	34.42	29.32	30.37	20.64	19.33
FeO	1.26	2.00	1.87	0.80	0.68	1.44	2.27	1.74	1.75	0.87	0.86
Fe_2O_3	3.47	3.59	2.35	1.10	1.07	1.82	2.76	2.34	2.19	1.16	0.58
TiO_2	0.14	0.13	0.21	0.15	0.08	0.07	0.12	0.10	0.06	0.04	Nil
MnO	0.02	0.04	0.03	0.01	0.02	0.04	0.19	0.22	0.09	0.06	Tr.
CaO	0.50	2.65	1.28	0.31	1.50	3.16	1.48	8.56	1.32	0.73	0.72
MgO	Tr.	Tr.	Tr.	0.06	0.60	0.71	0.09	1.18	0.82	0.62	0.29
K_2O	2.99	3.57	3.49	6.77	4.66	3.26	2.32	3.07	5.43	7.58	9.70
Na_2O	7.90	7.97	11.26	5.73	7.52	8.26	8.19	3.18	4.31	5.44	4.05
H_2O − 105°C	0.09	2.22	0.09	0.10	0.05	0.28	0.37	0.39	0.30	0.28	0.20
H_2O + 105°C	1.12	1.83	0.74	0.30	0.67	3.50	1.38	4.74	3.39	0.77	0.46
CO_2	Nil	0.52	0.69	0.11	1.07	1.62	1.34	0.56	1.02	0.32	0.35
P_2O_5	Tr.	Tr.	Tr.	Tr.	Nil	Tr.	Tr.	Tr.	Tr.	Tr.	Nil
	99.38	100.85	99.92	99.25	99.92	99.86	100.27	100.15	99.83	99.87	99.96
CALCULATED MODES											
Albite	60.05	37.7	34.0	42.5	58.7	24.2	43.0	11.0	14.1	37.2	26.2
Anorthite	2.5	10.0	2.0	0.8	0.6	5.6	..	4.1	2.5	1.7	1.1
Microcline	13.7	16.7	9.5	47.8	26.1	..	2.8	3.3	32.4	50.4	65.6
Nepheline	..	..	32.4	..	..	8.0	8.8	..	..	..	..
Corundum	5.3	1.8	..	..	..	4.0	15.3	..	12.4	1.5	..
Magnetite	5.1	5.3	3.5	1.6	1.6	2.6	4.2	3.3	3.3	1.9	0.9
Muscovite	9.6	6.4	16.5	5.6	6.4	24.0	12.0	21.6	8.0	4.8	4.0
Biotite	..	..	..	1.5	4.1	4.8	3.7	..	..	..	..
Spinel	..	..	..	..	..	..	..	1.7	..	..	..
Ilmenite	..	0.3	0.5	..	..	..	..	..	..	..	..
Chlorite	..	..	..	..	..	..	..	..	4.3	1.8	1.3
Carbonate	..	1.1	1.6	0.2	2.5	3.6	3.0	1.4	2.3	0.7	0.9
Clinozoisite	..	..	..	..	..	..	..	12.4	..	..	..
Zeolites	..	20.7	..	..	..	23.2	7.2	41.2	18.7	..	..
	96.7	100.0	100.0	100.0	100.0	100.00	100.0	100.0	100.0	100.0	100.0

* Analyst, D. A. Moddle.

† Analyst, W. H. Herdsman.

16. Hybrid buff corundum syenite from the farmyard of R. Gutz, Lot 34, Concession V, Brundenell Township

17. Hydronephelite-corundum gneiss taken directly on the strike of sample 16, 10 feet away

18. Nepheline gneiss taken directly on the strike of sample 17, 8 feet away

25. Hybrid alkaline syenite from the south end of the west wall of cut 6, Klondike workings

26. Hybrid alkaline syenite taken 3 feet below sample 25

27. Nepheline-corundum gneiss taken 3 feet below sample 26

20. Nepheline-corundum gneiss from the center of the east wall of cut 1, Klondike workings

21. Hydronephelite gneiss taken 1 foot above sample 20

22. Hybrid buff gieseckite-corundum syenite taken 1 foot above sample 21

23. Hybrid pink-buff Alkaline Syenite taken 1 foot above sample 22

24. Hybrid pink Alkaline Syenite taken 18 inches above sample 23

at the expense of the original minerals, principally nepheline. Although alumina was always extracted in the various stages of the transformation process, in places the intermediate transition stages are enriched in corundum. This corundum probably developed by crystallization of some of the alumina released in the transformation of the nepheline gneiss into syenite.

The quartz-arfvedsonite syenite ranges from light greyish green to dark red. This syenite facies is known only in a small lens-shaped zone, about 40 feet long with a maximum thickness of 12 feet, near the center of the east wall of cut 6 in the Klondike workings. This zone is enclosed in hybrid alkaline syenite.

The quartz-arfvedsonite syenite (Table 7, specimen 15) is mineralogically and texturally similar to the enclosing syenite except that in the quartz-arfvedsonite syenite (1) a minor amount of quartz is erratically distributed through the facies in thin, platy lenticles roughly aligned parallel to the banded structure of the surrounding complex; (2) arfvedsonite developed at the expense of the pyroxene; and (3) thin films of reddish iron oxides are common along cleavage planes and cracks in the feldspar, particularly adjacent to mafic mineral grains. The last feature, absent from the dark grey-green phases, is responsible for the dark red of the rock. Many plagioclase grains have well-developed rims of albite.

Contacts between the quartz-arfvedsonite syenite and the enclosing hybrid complex range from knife-sharp to gradational. Microscopic examination of such sharp contacts reveals a rather indefinite line or zone beyond which

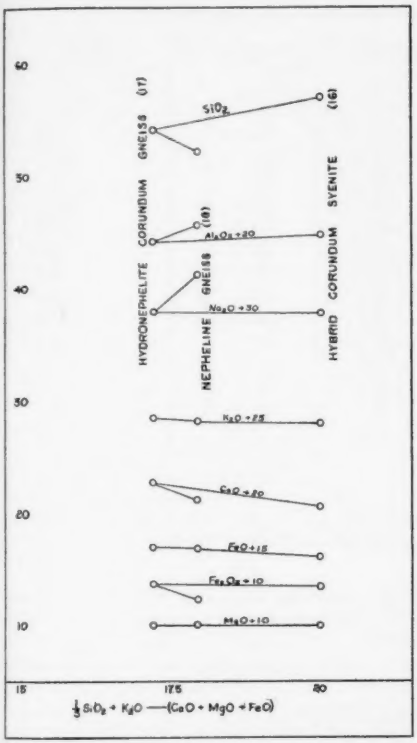

FIGURE 9.—LARSEN VARIATION DIAGRAM OF HYDRONEPHELITE CORUNDUM GNEISS, NEPHELINE GNEISS, AND HYBRID CORUNDUM SYENITE

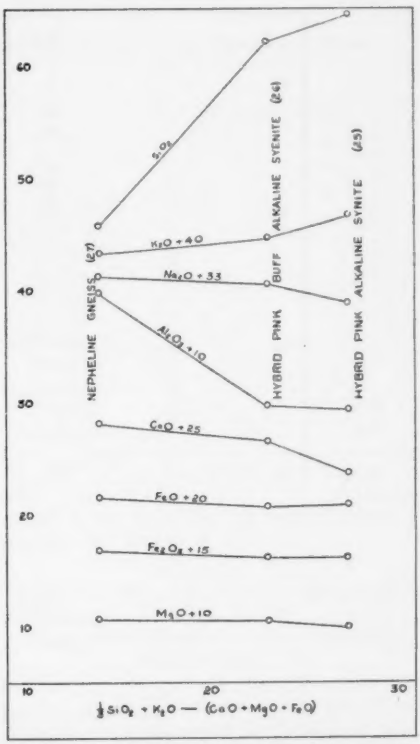

FIGURE 10.—LARSEN VARIATION DIAGRAM OF NEPHELINE GNEISS, HYBRID PINK-BUFF ALKALINE SYENITE, AND HYBRID PINK ALKALINE SYENITE

quartz, arfvedsonite, and reddish iron oxides are absent but across which mineral grains penetrate and interlock.

Comparison of the quartz-arfvedsonite syenite analysis with those of various specimens of the hydrid alkaline syenite shows no conspicuous variations in chemical compostion. The quartz-syenite contains a little more silica and a little less alumina, but otherwise the analyses are similar. It seems therefore that the quartz-arfvedsonite syenite is merely a phase of the hybrid alkaline syenite complex into which relatively more silica has been introduced.

In appearance, mineralogy, and texture the granite gneisses are similar to the hybrid alkaline syenite, except for the absence of quartz from the latter. In the granite gneiss quartz occurs in thin, platy lenses and streaks that roughly parallel the foliation of the gneissic complex. The granite-syenite contact is gradational along and across the strike; the two types appear to be genetically related. Hewitt (1953), Moyd (1949), Adams and Barlow (1910), and others have described the granitic rocks of the area and commented on their origin; the problem of the origin of the granite is beyond the scope of this paper. It must be noted here, how-

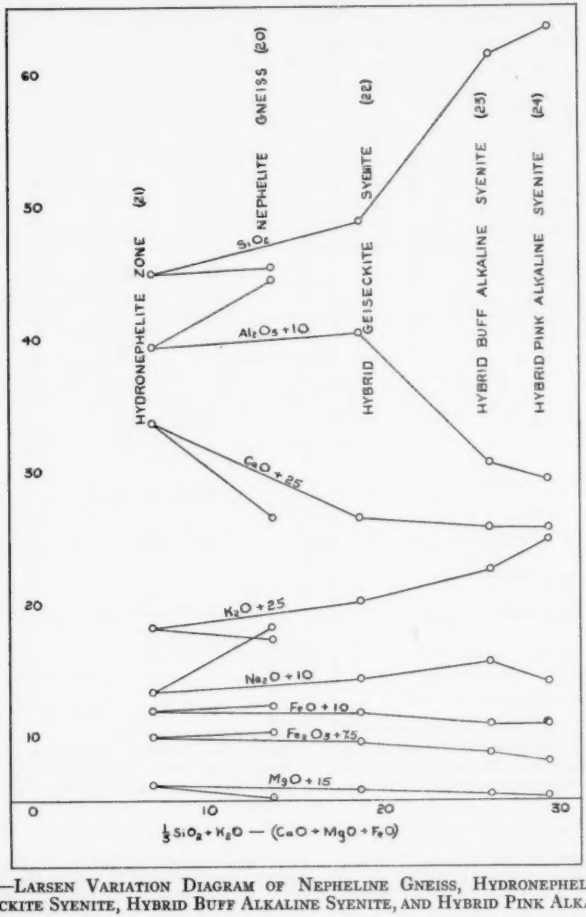

FIGURE 11.—LARSEN VARIATION DIAGRAM OF NEPHELINE GNEISS, HYDRONEPHELITE ROCK, HYBIRD GEISECKITE SYENITE, HYBRID BUFF ALKALINE SYENITE, AND HYBRID PINK ALKALINE SYENITE

ever, that nowhere in the corundum workings was granite gneiss seen in contact with any of the corundum-bearing rocks.

All the foregoing rock types are cut by stringers, dikes, and irregular masses of granitic and syenitic pegmatites, few of which are more than 10 feet wide, and most less than 5 feet wide. These pegmatites consist predominantly of large pink, buff, and grey-green rounded grains of microcline, microcline perthite, and plagioclase, up to 8 inches in diameter, set in a subordinate fine-grained granular matrix of pink and buff feldspar which forms thin films around and between the larger grains. The grey-green feldspar seems to be segregated into masses and zones, though there are all gradations between these zones and sections of the pegmatites rich in pink and buff feldspars. Hornblende is present as black, rather elongate, anhedral grains, from 2 mm up to about 10 cm long, which may constitute as much as 15 per cent of the rock by volume. These are scattered irregularly through the rock but tend to form relatively rich patches in the pegmatitic masses. The grey-green pegmatitic phases appear to be richer in hornblende than the pink phases. In some exposures splotchy segregations of granular quartz occur irregularly in patches up to 1 foot long and 6 inches wide. Vuggy openings in the pegmatite masses contain euhedral crystals of pink microcline, coarse books of biotite and muscovite, masses of greyish-white carbonate, and granular pyrite.

These granite and syenite pegmatites show the characteristics of true pegmatites and are believed to have crystallized from intrusive fluid, pegmatitic melts.

TABLE 7.—CHEMICAL ANALYSIS AND CALCULATED MODE OF QUARTZ-ARFVEDSONITE SYENITE

	15	A		15	A
SiO_2	65.31	61.93	Albite	43.5	38.0
Al_2O_3	16.02	19.78	Anorthite	1.7	3.5
FeO	1.26	1.78	Microcline	33.4	48.9
Fe_2O_3	2.20	1.79	Corundum		0.4
TiO_2	0.29	0.07	Magnetite	0.9	3.0
MnO	0.03	0.05	Muscovite		3.2
CaO	1.50	0.95	Biotite		1.6
MgO	0.63	0.28	Ilmenite	0.6	0.1
K_2O	5.64	7.03	Apatite		0.1
Na_2O	5.50	5.19	Quartz	10.7	
H_2O − 105°C	0.12	0.22	Pyroxene	3.9	
H_2O − 105°C	0.48	0.45	Arfvedsonite	2.9	
CO_2	1.07	0.17	Chlorite		0.8
P_2O_5	Nil	0.02	Carbonate	2.4	0.4
	100.15	99.71		100.0	100.0

15. Quartz-arfvedsonite syenite taken from the center of the east wall of cut 6, Klondike workings.
A. Average of analyses of hybrid alkaline syenite specimens 8, 9, 23, and 24 of Table 4.

ORIGIN OF THE CORUNDUM-BEARING ROCKS

Origin of the Scapolite-Andeclase-Nepheline Gneiss Complex

Any hypothesis for the origin of the scapolite-andeclase-nepheline gneiss complex must take the following factors into consideration: (1) The banded structure of the complex; (2) the irregular distribution of the pods, lenses, and patches of corundum-bearing rock; (3) the similarity of the scapolite rock to skarn zones in metasediments in the Grenville subprovince; (4) the restriction of pyroxene and hornblende to a few narrow corundum-free lenses and bands parallel to the banded structure of the complex; (5) and the sequence of events which appears to have taken place in the formation of the complex.

The banded structure and the nature of the scapolite rock suggest that the complex may have originally consisted of a sequence of stratified sedimentary rocks. That its present members do not represent simply recrystallized sedimentary rocks is suggested by their chemi-

cal compositions, particularly the presence of volatile constituents such as chlorine and fluorine in the scapolite rock. Bastin (1909, p. 445) has shown that in the majority of sedimentary rocks, magnesia predominates over other parts of the Grenville subprovince. In many exposures they are interbanded with crystalline limestones of varying degrees of purity. Table 8 shows analyses of seven sillimanite-garnet gneisses from various places in

TABLE 8.—CHEMICAL ANALYSES OF SILLIMANITE-GARNET GNEISS IN THE GRENVILLE SUBPROVINCE*

	1	2	3	4	5	6	7
SiO_2	61.96	57.66	74.70	58.68	60.33	49.61	55.18
Al_2O_3	19.73	22.83	8.88	16.17	17.17	22.00	20.70
Fe_2O_3			9.64	1.66	3.93	1.93	4.50
FeO	4.60	7.74		5.69	6.55	9.55	5.65
FeS_2	1.81	3.56	1.87	3.71	3.35	6.33	3.49
MgO	0.35	1.16	1.07	0.30	0.90	0.36	0.34
CaO	0.39	0.60	0.42	0.83	0.73	1.40	1.81
Na_2O	2.50	5.72	0.95	8.68	4.57	3.88	4.75
K_2O							
H_2O (+)	1.82	1.50	1.05	1.65	1.00	2.20	1.80
H_2O (−)							
CO_2				0.36			
TiO_2	1.66			1.39	1.52	2.00	1.72
SO_2							
P_2O_5				0.31	0.04	0.06	0.10
BaO							
MnO	tr.	tr.	0.50		0.09	0.05	0.05
C							
	99.55	100.77	99.08	99.43	100.18	99.37	100.09

* From Wilson (1925, p. 393, Table 11); Analyst, M. F. Connor.

1. Seigniory of DeRamsay, Joliette County, Quebec.
2. West shore of Trembling Lake, Papineau County, Quebec.
3. Darwin Falls, near Rawdon, Rawdon Township, Montcalm County, Quebec.
4. Opposite Montebello, Quebec, on the south shore of the Ottawa River, Prescott County, Ontario.
5. Lot 12, Range 1, Portland East Township, Papineau County, Quebec.
6. Lot 19, Range 12, Buckingham Township, Papineau County, Quebec.
7. Lot 19, Range 12, Buckingham Township, Papineau County, Quebec.

lime, potassium predominates over soda, and excess alumina and silica are present. Certainly excess alumina is present in the complex, but the other three criteria do not fit the pattern of metasedimentary facies. If these rocks were originally sedimentary, it is likely that considerable material was added and subtracted during the transformation into the present members of the complex.

In the metasedimentary sequence of the Brudenell-Carlow area, in which the corundum deposits are located, such aluminous facies as sillimanite-garnet gneisses and muscovite schists occur. These rocks, though nowhere abundant, are not uncommon in the area and appear to be similar to those described from this part of the Canadian Shield. The analysis of specimen 6, a low-silica, high-alumina gneiss, is plotted on the Larsen variation diagram (Fig. 12) together with the composite analyses of scapolite rock, andeclase rock, and nepheline gneiss shown in Figure 4.

It is evident from Figure 12 that the nepheline gneiss could have been derived from the sillimanite-garnet gneiss by the addition of soda and alumina and the extraction of magnesia and a little of the iron oxides. The quantities of silica, ferric oxide, lime, and potassium are all about the same in the two rocks. Similarly the andeclase rock could have been derived from calcareous phases transitional between the aluminus gneiss and crystalline limestone by

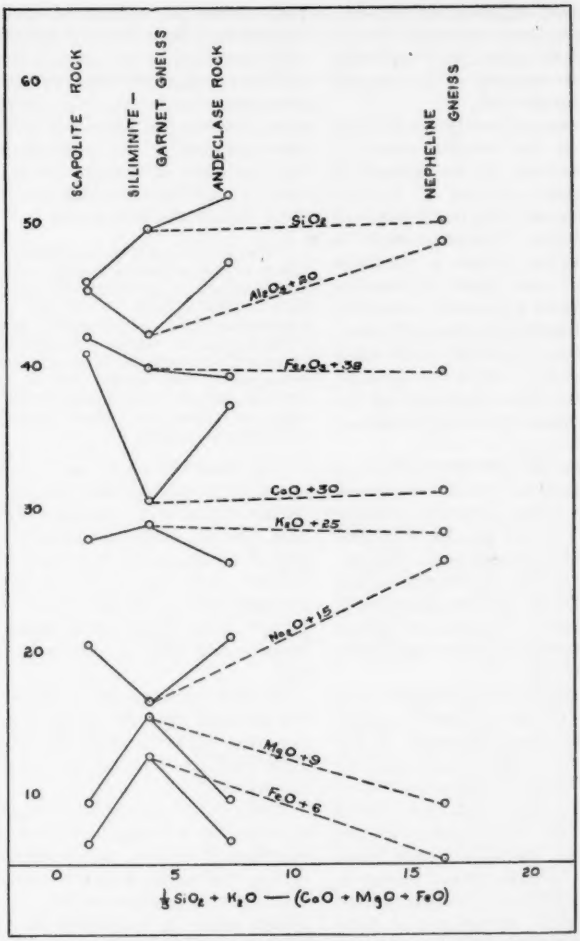

FIGURE 12.—LARSEN VARIATION DIAGRAM OF SILLIMANITE-GARNET GNEISS, SCAPOLITE ROCK, ANDECLASE ROCK, AND NEPHELINE GNEISS

the addition of silica, alumina, and soda and the extraction of magnesia, potassium, and iron oxides. The scapolite rock may have been derived from the more-or-less impure crystalline limestones interbanded with the sillimanite-garnet gneisses by the addition of silica, alumina, soda, halides, and possibly iron oxides and the extraction of lime, magnesia, and carbon dioxide. The transformation of an interbanded metasedimentary sequence of sillimanite-garnet gneiss and crystalline limestone into the members of the scapolite-andeclase-nepheline gneiss complex would require the introduction principally of soda and silica and possibly alumina; muscovite-rich lenses in the original metasedimentary sequence could have been a source for this oxide. Concomitantly with the introduction of these elements lime, magnesia, and potassium would have been extracted.

At a particular place in the complex the nature of the rocks formed by this metasomatism would depend partly on the composition of the hydrothermal solutions and partly on the composition of the original rock. The composition of the solutions would vary with

the nature of the rocks replaced, but the solutions appear to have been progressively enriched in soda at their source, since this oxide is more abundant in members of the complex younger than the scapolite rock.

Thus, the occurrence and erratic distribution of the corundum in the complex would be governed by two factors, (1) the amount of alumina in the original rock, and (2) the concentration of alumina and silica in the solutions at a given time and place. Corundum might be expected to crystallize where a relatively alumina-rich phase of the original sedimentary sequence was permeated by solutions saturated with this oxide and undersaturated with silica.

The metasomatizing solutions could have originated from the same deep-seated granitic magma chamber that was responsible for the emplacement of the main granite-syenite masses of the region.

In this hypothesis, the banded structure of the complex is attributed partly to original bedding and partly to the alignment of newly formed minerals. It is also possible that contemporaneous or later metamorphic differentiation of the chief mineral constituents further emphasized the banding. The concentration of hornblende and pyroxene in bands and zones is probably due to magnesia-rich layers and lenses in the original sediments.

The mineral and chemical composition of the andeclase rock are similar to certain igneous intrusive anorthosites found elsewhere in the Grenville subprovince. Table 9 and Figure 13 show the chemical compositions and modes of specimens of the andeclase rock and certain intrusive anorthosites. The anorthosites are slightly richer in lime, magnesia, titania, phosphorus, and sulfur and somewhat poorer in alumina and soda. Likewise the anorthosites contain slightly greater percentages of mafic minerals than the andeclase rock.

These facts compel attention, since corundum is known to occur in anorthositic rocks in various parts of the world, including India, Russia, and California, and these rocks are believed to be igneous intrusives. W. D. Harding (1947, p. 22) described an intrusive corundum-bearing anorthosite which occurs near Attewell Lake in Oso Township, Frontenac County, Ontario, about 90 miles southeast of the corundum deposits of Renfrew County and within the Grenville subprovince. This rock mass is about 5 miles northeast of similar anorthosite bodies studied by J. M. Harrison (Table 9). These anorthosites in Frontenac County are closely associated with and related to gabbroic rocks which are widespread in the Grenville subprovince. Such intrusive gabbroic rocks are fairly common in the general vicinity of the Haliburton-Bancroft belt of alkaline rocks throughout its length. No anorthosite intrusions, however, are known in this area, except those reported by Adams and Barlow (1910) in the townships of Burton, Dudley, Harcourt, Minden, and Dysart in Haliburton County. Of these Adams and Barlow said

> "They bear a striking resemblance to the albitic phase of the nepheline syenite, and like this are composed almost exclusively of plagioclase feldspar. This feldspar in these anorthosites, however, in all cases where it has been examined, has proved to be basic plagioclase, usually labradorite. The rock is, therefore, an anorthosite, and not a syenite, and has consequently been classed with the gabbros. It is doubtful, however, whether genetically this anorthosite is not a phase of a nepheline syenite rather than of the gabbro magma."

The possibility does exist, then, that the andeclase rock may have formed from an intrusive anorthositic magma. The andeclase rock does not exhibit intrusive relationships in any of its exposures; it is conformably interbanded with the scapolite and nepheline gneisses. This could have resulted by the injection of the anorthositic magma as sill-like bodies along bedding planes of the scapolite rock.

In most exposures the andeclase rock is surrounded and replaced by later hybrid alkaline syenites, so that any original intrusive relationships would be obscured by the development of the syenite.

There is no conclusive evidence that the andeclase rock crystallized from an intrusive anorthositic magma, unless detailed mapping of the Haliburton-Bancroft district discloses intrusive relationships between this facies and earlier rocks or establishes the presence of intrusive anorthosites in the area.

In this hypothesis the occurrence of the corundum is best explained as the result of magmatic assimilation of sedimentary facies that were locally rich in alumina. The scapolite rock would be the result of the contact metamorphism of calcareous metasediments. The nepheline gneiss could have formed as (1) a differentiated phase of the anorthositic magma, (2) a deuterically altered phase of the andeclase rock, or (3) a phase of the andeclase rock hydrothermally altered by later soda and alumina-rich solutions.

Evidence obtained in this study does not support one of these processes over the others.

In order to account for the erratic distribu-

TABLE 9.—CHEMICAL COMPOSITIONS AND CALCULATED MODES OF ANDECLASE ROCK AND ANORTHOSITES

	A	B	C	D	E	F	G
SiO_2	51.54	49.72	53.87	49.50	52.00	53.40	55.29
Al_2O_3	24.13	29.43	27.58	17.63	24.44	23.96	26.02
FeO	3.82	5.52	1.92	6.61	3.80	3.02	1.30
Fe_2O_3	1.61	0.60	1.37	5.34	1.36	0.91	1.60
TiO_2	0.18	0.12	tr.	1.80	0.80	0.77	0.52
MnO	0.15	0.18	0.08	0.08	0.02	....	N.D.
CaO	8.96	5.86	6.26	7.15	7.60	9.85	8.63
MgO	0.43	0.63	0.13	3.82	1.66	1.88	0.28
K_2O	0.72	0.85	1.68	1.80	1.13	0.80	1.03
Na_2O	5.70	5.42	6.22	4.52	4.54	4.17	5.71
H_2O − 105°C	0.18	0.19	0.15	0.09	0.04	0.04	0.10
H_2O + 105°C	1.65	0.74	0.42	0.38	0.40	0.62	0.13
CO_2	0.64	0.46	0.48	0.28	0.80	0.42	0.07
P_2O_5	0.13	nil	0.02	0.95	0.46	0.18	0.03
FeS_2	N.D.	N.D.	N.D.	0.34	0.51	....	0.05
Total	99.84	99.72	99.80	100.29	99.56	100.02	100.76
CALCULATED MODES							
Albite	49.2	47.2	58.0	35.90	35.95	73.0	48.27
Anorthite	31.7	26.4	28.1	18.77	27.61		43.17
Microcline	....	....	....	5.28	1.11	2.0	5.34
Corundum	....	7.5	2.5	....	....	....	....
Magnetite	2.4	0.9	1.9	6.11	1.97	....	2.32
Muscovite	5.7	3.2	4.0	2.98	3.63	....	....
Biotite	....	5.8	3.3	5.48	5.19	1.5	1.14
Ilmenite	....	....	....	2.81	1.52	2.0	0.99
Apatite	0.4	....	....	2.22	1.06	0.5	0.06
Chlorite	8.4	8.0	1.1	1.33	1.66	....	....
Carbonate	1.5	1.0	1.1	0.58	1.68	....	0.16
Sphene	0.7	....	....	0.78	....	Tr.	....
Hypersthene	....	....	....	4.61	2.24	7.0	....
Diopside	....	....	....	2.36	0.96		....
Hornblende	....	....	....	7.52	1.72	4.0	....
Pyrite	....	....	....	0.34	0.51	....	0.05
Scapolite	....	....	....	1.15	2.94	....	....
Epidote	....	....	....	0.28	....	....	....
Kaolin	....	....	....	1.14	8.78	....	....
Garnet	....	....	....	....	....	7.0	....
Quartz	....	....	....	0.70	2.34	3.0	....
Plagioclase	An_{39}	An_{36}	An_{33}	An_{33}	An_{42}	An_{52}	An_{45}

A. Specimen 1 of Table 2, corundum-free andeclase rock.

B. Specimen 3 of Table 2, corundum-bearing andeclase rock.

C. Specimen 4 of Table 2, corundum-bearing andeclase rock.

D. Average of analyses of 30 specimens taken at fairly regular intervals across the Tichborne gabbroic anorthosite intrusive; analyst, J. M. Harrison.

E. Gabbroic anorthosite from the center of the west end of Tichborne intrusive; analyst, Milton Hersey Company.

F. Composite sample of Whiteface gabbroic facies of anorthosite, Willsboro quadrangle, New York (Buddington, 1939, p. 30, Table 4, analysis 19); analyst, R. B. Ellestad.

G. Composite of three specimens from central portion of Wilkinson anorthosite; analyst, J. M. Harrison.

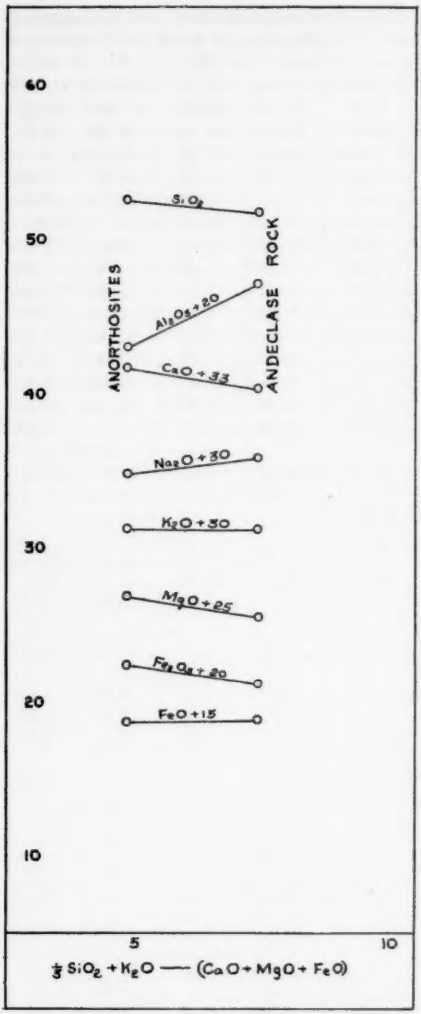

FIGURE 13.—LARSEN VARIATION DIAGRAM OF ANORTHOSITES AND ANDECLASE ROCK

tion of the corundum it is necessary to postulate original alumina-rich sediments where the complex now lies. These have been transformed into corundum-bearing rocks either by metasomatic alteration or by magmatic assimilation.

Origin of the Hybrid Alkaline Syenite

The pertinent facts bearing on the origin of the hybrid alkaline syenite are summarized briefly:

(1) The hybrid alkaline syenite complex is extremely and erratically variable in mineral composition and in fabric.

(2) In most places the syenite shows gradational contacts with the older rock types. Few sharp and no chilled contacts were seen in the field. Studies of such transitional zones indicate that microcline, the characteristic mineral of the hybrid syenite facies, developed by replacement of plagioclase, scapolite, or the hydronephelite of the earlier rock types or by replacement of relict pseudomorphs of these minerals. Chemical analyses of specimens taken across the gradational contacts indicate that the chemical changes involved in the transitions from the older rocks into the syenite were essentially the addition of potassium and silica and the extraction of lime and alumina.

(3) The syenite complex encloses numerous erratically distributed hybrid relicts of the older rocks which are oriented roughly parallel to the banded structure of the whole rock sequence.

(4) Nondilational dikes of the replacement type and stringers of syenite cut the earlier rocks.

(5) The hybrid alkaline syenite complex has a banded structure which appears to be inherited from the older rocks.

(6) The contact zones transitional between the hybrid syenite and the earlier rocks are generally richer in corundum than the original rocks; the corundum in these zones probably is due to the recrystallization of the alumina released here in the replacement of plagioclase, nepheline, scapolite, and muscovite by microline.

(7) Some hybrid, coarse-grained, inequigranular pegmatitic phases of the alkaline syenite are rich in corundum, but this mineral is absent from the great bulk of the complex.

Two modes of formation of the banded hybrid alkaline syenite complex might be considered. One hypothesis suggests that syenite formed from a liquid magma which was nonforcibly intruded into the scapolite-andeclase-nepheline gneiss complex, replacing a large part of it by assimilation and by stoping. No positive evidence of the intrusion of a liquid magma of this kind, such as dilational cross-cutting dikes of syenite in the older rocks or sharp chilled contacts of syenite against the older rocks, has been found.

In the other hypothesis the hybrid alkaline syenite complex formed by the metasomatic alteration of the scapolite-andeclase-nepheline gneiss complex by hydrothermal solutions enriched in potassium and silica. The evidence is

compatible with this hypothesis, and the writer prefers it. The source of the potassium- and silica-bearing hydrothermal solutions is attributed to those underlying portions of the crust in which the agents responsible for the emplacement of the main granite-syenite masses of the area were being generated.

Whatever process operated in the development of the syenite, the corundum in the contact zones between the older and younger rock complexes is to be attributed to the crystallization of the alumina which was released from the older rocks during their transformation into the syenite. Part of the alumina released crystallized as corundum in the contact zones, but much of it may have migrated with the solutions responsible for the rock transformations described to loci favorable for the development of the coarse-grained, corundum-rich, pegmatitic phases of the hybrid alkaline syenite complex. These phases show complete mineralogical, textural, and structural gradations into the enclosing syenite and thus appear to be pegmatites of the replacement type.

Summary and Conclusions

In Renfrew County corundum occurs in irregular, discontinuous, isolated zones and patches in a banded scapolite-andeclase-nepheline gneiss complex and in larger amounts in altered facies of this complex along its contacts with a younger hybrid alkaline syenite.

Originally the scapolite-andeclase-nepheline gneiss complex may have been (1) an intercalated sequence of calcareous and aluminous metasediments which were metasomatized by hydrothermal solutions rich in soda, alumina, and silica, or (2) a banded sequence of calcareous sediments intruded by sill-like masses of an anorthositic magma from which the andeclase rock could have solidified. In the latter the scapolite rock is regarded as a contact-metamorphic skarn developed in the calcareous sediments by the intrusion of the magma. The nepheline gneiss may have formed (1) as a differentiate of the anorthositic magma; (2) a deuteric alteration of the andeclase rock; or (3) an alteration of the andeclase rock by later hydrothermal solutions enriched in soda and alumina. There is no positive evidence that either of the processes outlined actually operated in the formation of the complex. Nevertheless, both are feasible and adequately explain the filed, mineralogical, and chemical relationships of the members of the complex. The writer believes that complete remapping and detailed study of the Haliburton-Bancroft belt of alkaline rocks is necessary before any conclusions can be made concerning the origin of the nepheline gneisses and associated rocks of the area. The origin of the corundum in the earlier rocks is attributed to the transformation of sediments locally rich in alumina into the corundum bearing portions of the complex either by metasomatic replacement or by magmatic assimilation.

After formation, the scapolite-andeclase-nepheline gneiss complex appears to have been subjected to at least a moderately high grade of dynamo-thermal regional metamorphism. In this period the banded structure of the complex may have been further emphasized by metamorphic differentiation of the chief mineral constituents.

The hybrid alkaline syenite appears to have formed by the metasomatic alteration of the rocks of the earlier complex. The banded structure and gneissic fabric of the syenite appear to have been inherited from the rocks that it replaced.

In the transformation of the scapolite, andeclase, and nepheline rocks into syenite, potassium and silica would have been added, and soda, alumina, and lime subtracted. The character of the chemical changes involved in the progressive development of the alkaline rocks is thus drastically altered at this point. The earlier changes pointed to a progressive enrichment in soda and alumina; the later changes show a progressive enrichment in potassium and silica at the expense of soda and alumina. It is possible that the scapolite-andeclase-nepheline gneiss complex and the hybrid alkaline syenite formed by the metasomatic action of hydrothermal solutions, which emanated possibly from a magma chamber where the large granite-syenite masses of the area were developed. Differentiation within such a magma chamber may have produced initial hydrothermal solutions rich in soda and alumina and later emanations rich in potassium and silica. Both soda-rich and potassium-rich end products of magmatic differentiation are known, but the timing and conditions of their respective formations relative to the late crystallization history of granite magmas is unknown.

The origin of most of the corundum in the alkaline rocks is attributed to the crystallization in the hybrid altered phases of the earlier complex of much of the alumina released in the transformation of the nepheline, andeclase, and scapolite rocks into microcline-rich syenite.

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Manuscript Received by the Secretary of the Society, February 18, 1955

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 68, PP. 1637–1658, 5 FIGS. DECEMBER 1957

THERMAL WATERS OF VOLCANIC ORIGIN

BY DONALD E. WHITE

ABSTRACT

Waters of widely differing chemical compositions have been considered at least in part volcanic in origin, and are commonly associated with each other in the same area. Do any or all of these types contain volcanic components, and if so, how are the different types derived?

To determine the probable characteristics of volcanic waters, the writer has selected hot-spring groups that are particularly high in temperature and associated heat flow, are associated with late Tertiary or Quaternary volcanism, and are therefore most likely to contain some water and chemical components of direct volcanic origin. Of the different types of water that occur in these groups, one of the most common is characterized chemically by a dominance of sodium chloride.

Isotopic evidence indicates that the contribution of water of direct volcanic origin is not large and is probably no more than 5 per cent in typical sodium-chloride springs.

The compositions of volcanic waters are believed to be determined by: [1] type of magma and stage of crystallization; [2] temperature and pressure of the emanation at different stages during and after departure from the magma; [3] chemical composition, relative quantity, and depth of penetration of mixing meteoric water and water of other origin; and [4] reactions with wall rocks. Although the type of magma and its stage of crystallization are of major interest and have been emphasized in the past, the outstanding characteristics of volcanic emanations at and near the surface of the earth seem to be controlled for the most part by the other factors.

Nonvolatile compounds are slightly to highly soluble in steam at high pressure, and high-density steam has solvent properties similar to those of liquid water. In the volcanic sodium-chloride waters, the high ratio of lithium to sodium and potassium is shown to indicate that alkalies were transported as alkali halides dissolved in a dense vapor. This in turn demands a deep circulation of meteoric water for steam to condense at high pressure and for the halides to remain in solution. The depth of circulation of meteoric water in the sodium-chloride spring systems is believed to be in the order of 2 miles. Where circulation of meteoric water is shallow, the vapors rise and expand at low pressure, which does not permit transport of substances of low volatility; some type of water other than the sodium-chloride type is formed. The common volcanic sodium-chloride waters are therefore concluded to be the diluted product of high-density emanations, modified by reactions with wall rocks and by precipitation of the less soluble components.

Emanations at high temperature and relatively low pressure consist almost entirely of steam and volatile components. Their compositions are therefore relatively simple, and their ability to transport matter of low volatility is very limited.

The sodium-chloride type is probably gradational into acid-sulfate-chloride waters. There is some evidence that, under conditions not well understood, sulfur may be emitted as SO_2, SO_3, or other sulfur species of intermediate valence, rather than as H_2S or S. Other major types of volcanic waters are called sodium bicarbonate, acid sulfate, and calcium bicarbonate; the first two tend to be distinct, but the calcium-bicarbonate type clearly grades into the sodium-chloride type. The writer concludes that, in general, all these are derived from the sodium-chloride waters as a result of physical environment or of reactions with wall rocks.

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INTRODUCTION

Scope

Waters of widely differing compositions have been considered volcanic in origin. Table 1 contains typical analyses of the principal types that have been recognized and shows the differences that are to be found in the major components. Are these waters entirely or in part of volcanic origin, and if volcanic, how are their greatly differing compositions explained? These questions have puzzled not only those geologists who have searched the literature for average or typical analyses, but also those who have studied hot springs in detail. Barth (1950, especially p. 39–43), for example, has considered some of the problems but has reached conclusions that are completely unacceptable to the writer.

The purpose of this paper is to describe the principal types of volcanic hot springs and to suggest processes that may account for their compositional differences.

Definitions

Thermal spring.—G. K. Gilbert (1875, p. 149) considered springs as thermal if their temperatures were more than 15°F. above mean annual temperature of the area. Stearns *et al.* (1935, p. 61) included some springs in their thermal list even though temperatures were not more than 10°F. above mean annual temperature. A temperature significantly above the mean annual temperature of the region characterizes the thermal springs. In general, 5°C. or 10°F. is considered significant.

Hydrothermal.—Of or pertaining to any water that is appreciably warmer (5°C. or more) than the surrounding environment. According to Holmes (1928, p. 121) the term refers to "magmatic emanations rich in water", and the same view is held by many geologists, but this was clearly not the intent of Morey and Niggli, (1913, p. 186–188), who first brought the term into popular use. It should refer to any water that is warm or hot relative to its surrounding environment, and it should have no genetic implications.

Magmatic water.—Water that is in, or is derived from, magma. It is a general term without restriction to depth or ultimate origin. Some magmatic water is probably juvenile, never having appeared previously at the surface, but much may actually be recycled, through remelting or partial melting of sedi-

mentary and volcanic rocks, or by absorption from intruded rocks.

Plutonic water.—Water that is in, or that has separated from, magma at considerable depth. The minimum depth is not known but is that of plutonic rocks—probably in the order of several miles.

Volcanic water.—Water that is in, or that has separated from, magma at the surface or at relatively shallow depth. The precise depth that separates volcanic from plutonic processes is not yet known; complete gradations are assumed. The waters with which this paper is concerned are in areas of recent or active volcanism. Considerations of heat flow appear to demand magma chambers at depths as great as 2–3 miles or somewhat more. The thermal activity is considered to be a phase of the volcanism.

Mixed water.—Many waters are believed to be mixtures of waters of different origins. If known, a mixture should ordinarily be identified by its components. Waters of deep origin, however, are ordinarily diluted near the surface by meteoric water. It is useful to refer to such mixtures by the deep component, which, if not diluted too extensively, largely determines the chemical and physical characteristics of mixture. In this paper the term volcanic water is used for all mixtures of volcanic and meteoric water even though the latter is greatly dominant. The deep component before dilution is called water of direct volcanic origin. Allen and Day (1935) applied the term "mixed" to acid waters high in chloride and sulfate, a usage that should not be continued.

Acknowledgments

The writer wishes to express his great indebtedness to James Healy of the Geological Survey of New Zealand, to C. J. Banwell, Dominion Physical Laboratory of New Zealand, and to Gunnar Bodvarsson of the Iceland Electricity Authority for stimulating discussions and correspondence concerning volcanic waters, and for reviews of the manuscript. Banwell has generously permitted use of Figure 1 of this paper. E. G. Zies, G. C. Kennedy, and R. M. Garrels have kindly read the manuscript and have offered many helpful suggestions and criticisms.

The writer owes much to his colleagues of the U. S. Geological Survey and in particular to Edgar Bailey, H. L. James, A. H. Lachenbruch, Ray Wilcox, P. F. Fix, H. R. Cornwall, C. H. Sandberg, P. E. Cloud, Jr., Siegfried Muessig, J. H. Feth, and Wilbur Burbank. None of these friends, however, is to be held responsible for the views that are expressed.

Evidence for Volcanic Water

A major problem is that of distinguishing volcanic or magmatic from non-magmatic waters. What criteria are conclusively diagnostic? The writer knows of no specific tag or label, such as the presence or absence of a particular element or isotope, to identify with certainty a volcanic water; in fact, he believes that no such tag exists.

Although it is possible to collect fumarolic gases, deep volcanic waters obviously cannot be sampled at their sources. Without prior definite knowledge of the compositions of deep emanations, nonchemical criteria must be used to point to those waters that are most likely to contain volcanic components. The most significant are held to be high temperatures and associated heat flow. In this paper, a few spring groups have been selected for critical examination, because of their abnormally high temperatures and heat flows (Table 2).

The quantity of uranium demanded to account for the heat flow at Steamboat Springs, Nevada, is approximately 300 million tons, an amount so large that magma rather than radioactivity is demanded. The thermal conductivity of bedrock granodiorite at Steamboat Springs is approximately 0.006 cal./cm sec. deg. If the quantity of heat that is flowing to the surface at Steamboat is at any depth transferred entirely by conduction through a cross-sectional area equal to Steamboat's surface area (5 sq. km), the geothermal gradient required is about 1°C. per 1¼ feet of depth. If this heat flow were transferred to the surface entirely by conduction, magmatic temperatures of 600°C. should exist at depths of only 750 feet.

In fact, however, the heat is transferred almost entirely in hot water that is dominantly meteoric in origin. It must be heated at depth by conduction, by high temperature (volcanic) stream, or by a combination of the two. If steam is lacking and meteoric water is heated by conduction the necessary thermal gradient is a function of the effective surface area of the walls of the fissure controlling circulation of the water. A fissure 2 km long and 1 km deep has a maximum effective surface area (both walls) of 4 square km; the average horizontal temperature gradient in the walls must then be about 1°C. per foot. Even a fissure 5 km long and .3 km deep requires an average horizontal gradient of 1°C. per 7½ feet. These gradients,

TABLE 1.—ANALYSES OF HOT SPRINGS THAT ARE CHARACTERIZED BY HIGH TEMPERATURES AND ASSOCIATED HEAT FLOW, IN PARTS PER MILLION

	Steamboat Springs Washoe County Nevada[1]	Morgan Springs Tehama County California[2]	Norris Basin Yellowstone Park Wyoming[3]	Upper Basin Yellowstone Park Wyoming[4]	Well 4 Wairakei New Zealand[5]	Norris Basin Yellowstone Park Wyoming[6]	Frying Pan Lake New Zealand[7]	Well 5 Wairakei New Zealand[8]	Acid Pool, Norris Yellowstone Park Wyoming[9]	Mammoth Yellowstone Park Wyoming[10]
Type of water	Sodium chloride	Sodium chloride	Sodium chloride	Sodium chloride	Sodium chloride	Acid sulfate chloride	Acid sulfate chloride	Sodium bicarbonate	Acid sulfate	Calcium bicarbonate
Temp. °C.	89.2	95.4	84	94.5	>100	87	59	>100	70	70.5
pH	7.9	7.83	7.45	8.69	8.6	2.47	3.0	6.7	2.2	6.9
SiO_2	293	233	529	321	386	496	428	191	364	56
Fe				Tr.		0.8	3		2.9	
Al				0		1.5	4		1.6	
Ca	5.0	79	5 8	4	26	6.5	17	12	2.6	209
Mg	0.8	0.8	0.2	Tr.	<0.1	nil	4	1.7	1.0	78
Sr	0.1	10								
Na	653	1398	439	453	1130	243	607	230	27	129
K	71	196	74	17	146	61	70	17	24	56
Li	7.6	9.2	8.4		12.2	3.2		1.2	0.1	1.4
NH_4	<1	<1	0.1	0	0.9	3.4		0.24	10	
As	2.7	2.2	3.1							
Sb	0.4	0.0	0.1							
CO_3	0	0	0	66						
HCO_3	305	52	27	466	35	nil	(nil)	670	nil	526
SO_4	100	79	38	15	35	454	262	11	482	529
Cl	865	2427	744	307	1927	408	953	2.7	6.0	169
F	1.8	1.5	4.9	21.5	6.2			3.7		
Br	0.2	0.8	0.1							
I	0.1	<0.1	<0.1							
B	49	88	11.5	3.7	26	6.9	14	0.5	1.5	4.4
S_2O_3				2						
H_2S	4.7	0.7	0	0	1.1		nil	0		2.4
CO_2					11			0		
Sum	2359	4577	1885	1676	3742	1684.3	2362	1141.04	922.7	1760.2

Sum	2359	4577	1883	1676	3742	1664.5	2582	1111.1	1111.1	1111.1
Ratios										
HCO_3/Cl[11]	0.35	0.021	0.036	1.9	0.018	0.000	0.000	250	0.00	3.1
SO_4/Cl	0.12	0.033	0.051	0.049	0.018	1.1	0.28	4.1	80	3.1
F/Cl	0.0021	0.0006	0.0066	0.070	0.0032			1.4		
Br/Cl	0.0002	0.0003	0.0001							
I/Cl	0.0001	<0.00004	<0.0001							
B/Cl	0.057	0.036	0.015	0.012	0.013	0.017	0.015	0.2	0.25	0.026
K/Na	0.11	0.14	0.17	0.038	0.13	0.25	0.12	0.074	0.89	0.43
Li/Na	0.012	0.0066	0.019		0.011	0.013		0.0052	0.004	0.011
Ca + Mg/Na + K	0.0080	0.050	0.012	0.008	0.020	0.021	0.031	0.055	0.071	1.6

[1] Spring 8, collected 8/9/49, analyzed by W. W. Brannock, U. S. Geological Survey. Sr by spectrographic analysis but is probably about 0.6 ppm judging from samples collected at Steamboat in 1954.

[2] Black Growler Spring, collected 7/29/49, analyzed by W. W. Brannock, U. S. Geological Survey. Sr by spectrographic analysis.

[3] Unnamed spring with periodic discharge depositing abundant silica, 200 feet southwest of Pearl Geyser. Collected 8/13/51, analyzed by P. W. Scott and W. W. Brannock, U. S. Geological Survey.

[4] Sapphire Pool (Allen and Day, 1935, p. 103, 249). Analyzed by E. T. Allen.

[5] Erupting well in eastern part of Wairakei area (Wilson, 1955, p. 37).

[6] Green Dragon Spring, collected 8/27/54. Analyzed by Henry Kramer. Estimated discharge, 40 gpm.

[7] Estimated discharge "greater than 1,000 gpm." (Grange, 1937, p. 93, 103, analysis 28).

[8] Erupting well in western part of Wairakei area (Wilson, 1955, p. 37).

[9] Spring with seeping discharge, 45 feet west of Norris Basin drill hole described by Fenner (1936, p. 282–285). Collected 8/25/54, analyzed by Henry Kramer.

[10] Blue spring, crest of Main Terrace, collected 8/25/54, analyzed by Henry Kramer.

[11] All carbonate computed as bicarbonate.

if continued for considerable distances under steady-state conditions, require magmatic temperatures within about 600 feet of the fissure for the first example and 4200 feet for the second.

necessary to supply stored heat at submagmatic temperatures.

The volumes, length of time, and required gradients also suggest that an inert crystallizing magma chamber does not satisfy the demands.

TABLE 2.—MAXIMUM MEASURED TEMPERATURES AND ESTIMATED TOTAL HEAT FLOW OF SOME AREAS THAT CONTAIN ANALYZED THERMAL WATERS OF PROBABLE VOLCANIC ORIGIN

Locality	Max. temps., degrees C.		Heat flow 10^6 cal./sec.	Equiv. km² of "normal" area[1]	Approx. size of thermal area, km²	Multiple of "normal" for area	Yearly requirement of magma, km³[2]
	Surface	Drill Holes					
Steamboat Springs, Nevada[3]	boiling	172	7	600	5	120	0.00047
Morgan Springs, California[4]	boiling						
Yellowstone Park							
Norris Basin	boiling	205[5]	8[6]	660	3	220	0.00053
Upper Basin		180[5]	90[7]	7500	10	750	0.0060
Mammoth and Hot River area	75°		34[8]	2800	8	350	0.0023
New Zealand							
Wairakei area	boiling	270	110[9]	9200	15	610	0.0075
Frying Pan Lake	55°		23[10]	1900	1	1900	0.0015

[1] Heat flow from "normal" areas is about 1.2×10^4 cal./sec. sq. km (Birch, 1954).

[2] The magma is assumed to be granite initially liquid at 900° C. and is assumed to cool and be entirely crystalline at 500° C. The mean heat of crystallization is assumed to be 75 cal./gm (Goranson, 1942, p. 235–236) and the heat capacity through this temperature range, ¼ cal./gm° C. (Goranson, 1942, p. 237–238). The total available heat of the magma above 500° C. is thus 175 cal./gm, or about 4.7×10^{17} cal./km³, assuming a density of 2.7.

[3] Data, in part not previously published.

[4] On the south border of Lassen Volcanic National Park, an area with historic volcanic eruptions (Day and Allen, 1925, p. 98–100, 113).

[5] Fenner, 1936, p. 237, 291.

[6] Allen and Day, 1935, p. 135. Discharge, 39 liters/sec. of water containing 3.1×10^6 cal./sec. excess heat at discharge temperatures. If all has cooled from the maximum recorded fluid temperature of 205° C. (at depth of 246 feet), the heat flow is 7.8×10^6 cal./sec. This is a more realistic figure and allows for very abundant steam flow at Norris.

[7] Allen and Day, 1935, p. 135. Discharge, 518 liters/sec. of water containing 44×10^6 cal./sec. at discharge temperatures. If all has cooled from the maximum recorded fluid temperature of 180° C. (at depth of 406 feet), the total heat flow is 90×10^6 cal./sec.

[8] Allen and Day, 1935, p. 135, 386. Heat flow in discharging water, probably close to total because temperatures are relatively low with little heat loss in vapor or by conduction.

[9] Approximate average of physical methods (133×10^6 cal./sec., Healy, 1953; Banwell, 1955, p. 50) and chemical methods (82×10^6 cal./sec., Ellis and Wilson, 1955, p. 629).

[10] Assuming 1000 gpm, 55° C. at outlet (Grange, 1937, p. 92), and mean annual temperature of 15° C., the excess heat content of the flowing water is 2.5×10^6 cal./sec. The evaporative heat loss from the lake, about 5 acres in area, is approximately 20×10^6 cal./sec., according to John Banwell of the Dominion Physical Laboratory, New Zealand (Personal communication).

For young spring systems, the necessary heat could come from a stored supply, but Steamboat Springs, for example, has been active for all the post-Pleistocene, and its age is more probably in the order of 100,000 years. The present heat flow, if representative of such an interval, requires a total volume of magma of 47 km³ (Table 2). A much larger volume is

A magma chamber with convection is indicated in order to maintain high temperatures near the chamber walls.

The necessary heat can also be supplied entirely by volcanic steam. The temperature of the hot spring water at shallow depth in the Steamboat Springs system, for example, is about 170°C., and its enthalpy (or heat con-

tent above 0°C.) is about 170 cal./gm (Fig. 1). If steam at the critical point is heating cold meteoric water, approximately 35 per cent of volcanic steam, with an enthalpy of 500 cal./gm., is required. Steam at any likely volcanic temperature cannot have an enthalpy of more than about 1000 cal./gm. If such steam supplies all the heat, about 17 per cent is required.

These calculations clearly indicate the need for magma. They also point out the function that volcanic steam may play in supplying at least part of the heat. Regardless of the relative importance of conduction and steam in supplying heat, a magmatic source is clearly required for old thermal systems. If magma contains water, and water is evolved during cooling and crystallization, then the springs of Table 2 are likely places to look for volcanic water.

Lindgren (1933, p. 47–49, and earlier work) was one of the first to conclude that the varied waters found intimately associated in these volcanic environments contain relatively high concentrations of substances such as CO_2, sulfur, boron, chlorine, and alkali metals. In general, this paper concludes that most of these waters are derived from dense supercritical vapor containing much sodium chloride. In a companion paper (White, 1957), the sodium-chloride waters from volcanic environments are compared with other waters high in sodium chloride. Chemical criteria then become apparent for distinguishing volcanic sodium-chloride waters from non-volcanic waters.

Near the surface, waters of volcanic association clearly consist dominantly of meteoric water. This has long been suspected by most geologists, but strong isotopic evidence for this view is shown by Craig, Boato, and White (1954; 1956; and forthcoming papers). The surface waters of New Zealand, Lassen Park, Yellowstone Park, Steamboat Springs, and Iceland differ isotopically from each other, but the hot springs of each area are very similar to the surface water of the same area. In the waters that have been studied, the volcanic component probably does not exceed 5–10 per cent of the total, and the isotope evidence does not actually demand the existence of any volcanic water. If the primary volcanic emanations have salinities similar to or greater than that of sea water, and are diluted 10–20 times by meteoric water, all data pertaining to heat flow, chemical composition, and isotopes are found to be mutually compatible. If, in view of the isotopic evidence, it is assumed that no hydrous volcanic emanations are involved, then all the heat flow must be accounted for by conduction, and most chemical components must be derived from wall rocks. Some quantitative aspects of this possibility have already been described, and others will be examined. The possibility is found to be very unlikely.

Factors that Probably Influence Chemical Composition

The compositions of volcanic waters and vapors are believed to be determined by the following: [1] type of magma and stage of crystallization; [2] temperatures and pressures of the volcanic emanation during and after departure from the magma; [3] the chemical composition, relative quantity, and depth of penetration of mixing meteoric water or water of other origin (White, 1957); and [4] reactions with wall rocks. The type of magma and its stage of crystallization are of major interest, but the dominant characteristics of volcanic emanations at and near the surface of the earth seem to be determined to a major extent by the other factors.

The physical state of volcanic water as it leaves the magma and while it migrates toward the surface is believed to account for the greatest differences in composition. Recent work has demonstrated that many compounds of low volatility are soluble in water vapor near and above the critical point (Schröer, 1927; Kennedy, 1950; Morey, 1953; 1954; Morey and Hesselgesser, 1951a; 1951b; Olander and Liander, 1950; Straub, 1946). Smith (1953, p. 25–30) and Morey (1957) have reviewed the recent evidence. In general these compounds have very low solubilities in steam of low density, but the solubilities increase with increasing density of the steam. At constant density solubilities increase with temperature, but at relatively low constant pressures they decrease with increasing temperature because of decreasing density of the vapor. Of particular importance is the relative insolubility of NaCl and other alkali halides in steam at low pressure and density, but solubilities increase greatly near the critical point of water (Schröer, 1927; Straub, 1946; Olander and Liander, 1950).

Figure 1 is a pressure-temperature-enthalpy diagram for water and steam. Solubility data for NaCl in supercritical steam (Olander and Liander, 1950) are superposed on the diagram without regard for effects on the enthalpy and critical relations.

Volcanic Emanations at or Near the Surface

Superheated Volcanic Fumaroles

Volcanic fumarole gases consist almost entirely of components of relatively high volatility. Components that are nonvolatile at the fumarole temperatures and that do not form somewhat volatile halogen compounds are very rare. The halogens are transported largely as halogen acids (Zies, 1929) and possibly as free halogens (Shepherd, 1925, p. 366; 1938, p. 321, 326), although sublimates of KCl and NaCl were found by Lacroix (1906) in high-temperature fumaroles at Vesuvius (700°–800°C.). Many but not all high-temperature fumarolic gases give acid reactions when condensed (Sborgi, 1939).

Volcanic fumarole gases are ordinarily superheated, and temperatures are far higher than equilibrium temperatures of saturated water vapor at the existing pressures. Nonvolatile substances have low solubilities in water vapor of such low density. Under favorable conditions, as in some crater lakes, the steam and acid-forming gases are no doubt completely condensed by meteoric water. The mixture, with free halogen and sulfur acids, then attacks wall rocks and dissolves most metallic elements, roughly in proportion to their abundance in the rocks.

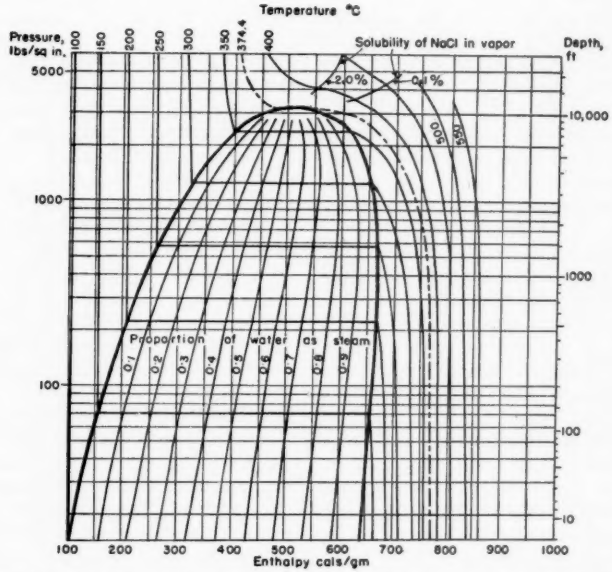

FIGURE 1.—Pressure-Temperature-Enthalpy Diagram for Steam and Water

(Diagram prepared by C. J. Banwell, Dominion Physical Laboratory, D. S. I. R., New Zealand.) Solubility of NaCl in gas from Olander and Liander (1950). Depth assumes hydrostatic pressure, boiling throughout Effects of NaCl on critical temperature and enthalpy have been neglected.

Sodium-Chloride Waters

Slightly acid to alkaline waters dominated by sodium chloride and bicarbonate constitute a group that was called alkaline waters by Allen and Day (1935, p. 71–72), but are here called sodium-chloride waters. In the past the halogens were generally assumed to be transferred as volatile acids in steam, as in Figures 2*B* and 3*B*. When the steam was condensed, the acids reacted with the wall rocks and were neutralized. Some sodium-chloride waters may form in this way. The acid-sulfate-chloride waters, such as those of Norris and Frying Pan Lake (Table 1) are logical suspects, but they are also characterized by particularly high sulfate. The acidity, as will be seen, appears to be due to sulfuric rather than to hydrochloric acid. In

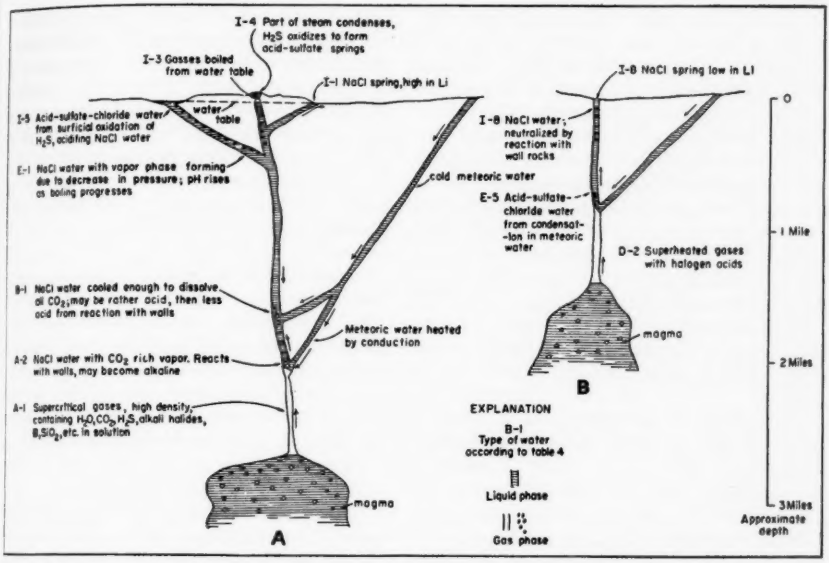
I-4 Part of steam condenses, H_2S oxidizes to form acid-sulfate springs
I-3 Gasses boiled from water table
I-1 NaCl spring, high in Li
I-8 NaCl spring low in Li
I-5 Acid-sulfate-chloride water from surficial oxidation of H_2S, acidifies NaCl water
water table
E-1 NaCl water with vapor phase forming due to decrease in pressure; pH rises as boiling progresses
cold meteoric water
I-8 NaCl water; neutralized by reaction with wall rocks
E-5 Acid-sulfate-chloride water from condensation in meteoric water
D-2 Superheated gases with halogen acids
B-1 NaCl water cooled enough to dissolve all CO_2; may be rather acid, then less acid from reaction with walls
Meteoric water heated by conduction
A-2 NaCl water with CO_2 rich vapor. Reacts with walls, may become alkaline
A-1 Supercritical gases, high density, containing H_2O, CO_2, H_2S, alkali halides, B, SiO_2, etc. in solution
magma
A
B
EXPLANATION
B-1 Type of water according to table 4
Liquid phase
Gas phase
0
1 Mile
2 Miles
3 Miles
Approximate depth

FIGURE 2.—SUGGESTED GENESIS OF VOLCANIC SODIUM-CHLORIDE WATERS BY TWO MECHANISMS

Method A seems to be the most common. Widths of fissures greatly exaggerated to permit distinguishing liquid and gas phases. Sodium-chloride water of probably high sulfate content can also be formed by sufficient reaction of acid-sulfate chloride water of Figure 3 with wall rocks.

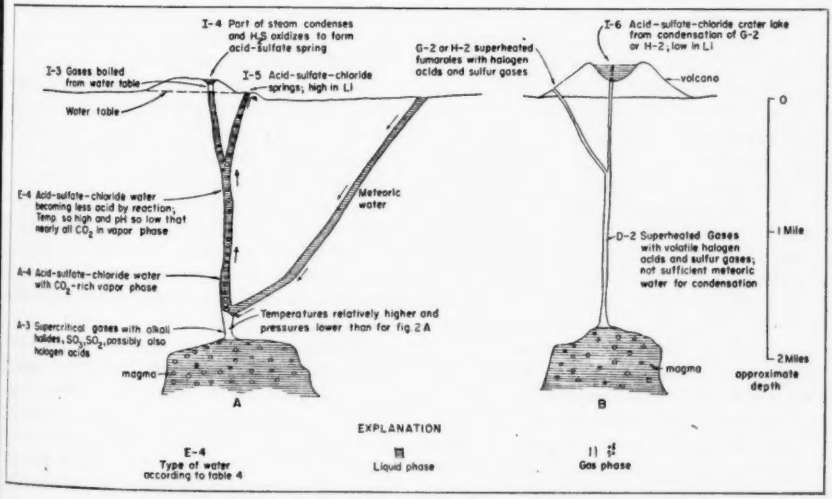
I-4 Part of steam condenses and H_2S oxidizes to form acid-sulfate spring
I-6 Acid-sulfate-chloride crater lake from condensation of G-2 or H-2; low in Li
G-2 or H-2 superheated fumaroles with halogen acids and sulfur gases
I-3 Gases boiled from water table
I-5 Acid-sulfate-chloride springs; high in Li
volcano
Water table
E-4 Acid-sulfate-chloride water becoming less acid by reaction; Temp. so high and pH so low that nearly all CO_2 in vapor phase
Meteoric water
D-2 Superheated Gases with volatile halogen acids and sulfur gases; not sufficient meteoric water for condensation
A-4 Acid-sulfate-chloride water with CO_2-rich vapor phase
A-3 Supercritical gases with alkali halides, SO_2, SO_2, possibly also halogen acids
Temperatures relatively higher and pressures lower than for fig. 2A
magma
A
B
EXPLANATION
E-4 Type of water according to table 4
Liquid phase
Gas phase
0
1 Mile
2 Miles
approximate depth

FIGURE 3.—SUGGESTED GENESIS OF ACID-SULFATE-CHLORIDE WATERS

A third method is illustrated in Figure 2*A*, I-5. Widths of fissures greatly exaggerated; lava filling of volcanic vent of *B* not shown.

view of their acidity, their surprisingly low content of calcium and magnesium (Table 1) is not consistent with the theory that their alkalies and silica were obtained entirely or even largely by leaching of wall rocks. Minor leaching of alkalies, however, is probable.

Superficial alteration by sulfuric acid is not uncommon in oxidizing sulfide deposits and hot springs (White, 1955). Deep alteration by sulfuric acid seems to be relatively rare. Of other hydrothermal alterations that may be caused by acid solutions, CO_2 rather than HCl is indicated as the active component.

When volcanic steam is evolved under sufficient pressure, the halogens are soluble in the dense vapor as alkali halides (Schröer, 1927; Ingerson, 1934; Straub, 1946; Olander and Liander, 1950), and probably little or no dissociation occurs. The alkali ratios of most if not all sodium-chloride springs favor transport of the halogens as alkali halides dissolved in the magmatic vapor phase (Table 1; Fig. 2*A*). Lithium, relative to other components, is higher in the chloride springs than in any other known type of natural water (White, 1957). The Li/Na ratios are in the order of 0.01 in these springs, 0.0008 in average igneous rocks (Rankama, 1954, p. 135), and perhaps as much as 0.005 in rhyolites in the western United States (Coats, 1956, p. 76). If the alkali content of the volcanic sodium-chloride springs is a result of leaching, a strong selective removal of lithium is necessary. As will be seen, this is not found in the acid-sulfate springs, and there is no reason to suspect that halogen acids could leach lithium so selectively in the required amounts and over the probable long lives of some of the spring systems.

For example, at Steamboat Springs, Nevada, thermal water with an average lithium content of 8 ppm is being discharged at and below the surface at a rate of about 700 gpm. Lithium is discharged at a rate of 1.1×10^7 gms or 11 metric tons per year. If Steamboat granodiorite, with an average lithium content of about 30 ppm, is completely leached of its lithium, 140,000 cu.m. are required per year. This is equivalent to 14 km^3 of granodiorite over a period of 100,000 years, which is believed to be the probable age of the spring system. Stated in another way, each pound of water must come in contact with a quarter of a pound of fresh rock and leach all the lithium from it. This may be conceivable in a new spring system where much surface area of unaltered rocks is accessible in fault and breccia zones but is highly improbable in a system as old as that of Steamboat Springs. The accessible altered rocks, moreover, indicate that lithium may be added rather than leached. Rocks containing secondary micas appear to be particularly high in Li, and as much as 300 ppm is reported in some analyses. A much more reasonable hypothesis to explain all the evidence is that lithium and the other alkali metals were concentrated in residual magma and were then transported as soluble alkali halides in a dense vapor phase. The writer suspects that the alkali metals in the emanations that leave silicic magmas are in the approximate proportions, by weight, of 1 Na:0.5 K:0.25 Li. The proportions found in surface springs (Table 1) are changed by reactions, including cation exchange with wall rocks. The other alkali metals, rubidium and cesium, probably remain for the most part in the magma and are fixed in silicate minerals. Fluorine may be relatively low in high-pressure emanations for the same reason.

Much silica is no doubt transported in solution in the dense vapor phase (Kennedy, 1950; Morey and Hesselgesser, 1951b; Morey, 1954), and additional silica is dissolved from the wall rocks. Volcanic sodium chloride waters have the highest silica content of known natural waters (White, Brannock, and Murata, 1956).

Meteoric water is believed to circulate to depths that are in the order of 10,000 feet to provide the hydrostatic pressures and vapor densities required to transport alkali halides in solution rather than as volatile compounds (Olander and Liander, 1950, p. 1443). For a column of water that is everywhere at its boiling point, hydrostatic pressure is equal to the critical pressure at a depth of about 2 miles (Fig. 1). Where vapor pressure of the emanation exceeds the hydrostatic pressure, ground water cannot penetrate to condense the vapor or to dissolve its low-volatile components. Condensation of the vapor at high pressure seems to be an essential stage in the continuous transfer of substances like sodium chloride from the magma to the surface.

Where the vapor channel is very restricted and low in permeability, opening suddenly into permeable channels filled with meteoric water, it is possible for the zone of intermixture to be less than 10,000 feet in depth and still maintain the relationships essential for continuous transport of alkali halides. The minimum depth in these special circumstances is about 3000 feet, where lithostatic pressure is equal to the critical pressure of water.

Drilling at Wairakei, New Zealand (Healy, 1953; Banwell, 1955; Ellis and Wilson, 1955)

to depths of more than 3000 feet indicates that water, dominantly of meteoric origin, circulates to depths that are unknown but are certainly greater than the drill holes. Vapor pressures with rare exceptions do not exceed hydrostatic pressures and are always far below lithostatic pressures. Meteoric water and volcanic steam apparently mix with proportions that attain a single liquid phase at a temperature that is close to 270°C. The water rises as a liquid phase to depths of 2000–1500 feet where hydrostatic pressure becomes sufficiently low to permit a vapor phase, at least locally.

Drilling at Steamboat Springs, Nevada, to depths as great as 685 feet has revealed a similar situation, except that the mixing temperature of meteoric water and volcanic steam is probably little above 175°C., and the near-surface vapor phase is limited to the upper 350 feet of the spring system.

Some geologists may object to the concept that meteoric water circulates to depths of 2 miles or more. The dryness of many deep mines is commonly cited as evidence against deep circulation, but this proves only that present permeabilities are low and that deep circulation does not occur to a prominent extent under existing conditions. Most of the examples are not from epithermal deposits; in addition, the deposition of vein material may have greatly decreased original permeabilities.

The paucity of fluorine relative to chlorine may be due to condensation of the volcanic fluid of the sodium-chloride springs at sufficient depth and with sufficient distance and travel time, so that much F can be fixed in hydrothermal micas and fluorite. Zies has been impressed with the abundance of fluorine relative to chlorine in volcanic fumarole gases and igneous rocks (Zies, 1929, and personal communication). In these substances, chlorine is seldom greatly dominant over fluorine. In contrast, the highest F/Cl ratio of the sodium-chloride springs of Table 1 is only 0.07. The fluoride content of these waters is seldom more than 15 ppm and is consistently lower in the nearly neutral springs containing appreciable calcium.

At all temperatures below the critical temperature of steam (374.4°C.), the water of the sodium-chloride springs is either in the liquid phase or is in part in saturated steam (Fig. 2*A*). Steam in contact with liquid water cannot be superheated, but the thermodynamic relations of steam and water are such that steam separated from water at high temperature and remaining out of contact with water can become slightly superheated. The maximum superheat obtainable in this way is when steam at about 250°C. is removed from contact with water and is allowed to expand to atmospheric pressure without loss of heat (Fig. 1); the resulting steam has a temperature of about 170°C., or 70° of superheat.

At temperatures appreciably below the critical temperature, all the low-volatile components that had been transported in solution in the high-density volcanic steam are dissolved in the liquid phase. A vapor phase, if present, contains only volatile components such as steam, CO_2, sulfur gases, and nitrogen.

Acid-Sulfate-Chloride Waters

Some volcanic hot springs are similar in composition to the near-neutral or alkaline sodium-chloride springs except that their pH's are less than 5, combined CO_2 is therefore virtually absent, and sulfate is relatively high.

Acid waters of rather similar compositions can probably originate in four different ways: [1] mixing of different sodium-chloride and acid-sulfate waters; [2] near-surface acidification of near-neutral sodium-chloride waters by oxidation of H_2S (Fig. 2*A*, type I-5); [3] deep condensation of dense vapors that contain alkali halides and oxidized sulfur (Fig. 3*A*), probably with little or no free halogen acids; and [4] surficial condensation and oxidation of low-density volcanic gases containing halogen acids and sulfur (Fig. 3*B*). Allen and Day (1935, p. 73, 460–504) used the term "mixed waters" for what is here called the acid-sulfate-chloride type. They were believed to form by the first or second method, the latter involving acidification of "alkaline" sodium-chloride water as a result of surficial oxidation of H_2S in the gases (Table 3). Low rates of discharge of water and inadequate flushing, combined with abundant discharge and oxidation of H_2S contained in the gases were viewed as favoring the formation of these acid waters. The present writer agrees that many acid-sulfate-chloride springs originate in this way. The alkali ratios in the waters are largely inherited from the parent sodium-chloride waters. The K/Na ratios may be modified, but important changes in the Li/Na ratios are unlikely.

A few acid springs are similar to the above in composition, but their discharges are so high that surficial production of sulfuric acid in the required quantities is unlikely; their origin is not yet well understood, but the mechanism suggested in Figure 3*A* may be applicable.

Two outstanding examples have been described briefly by White (1955, p. 106–107). The Green Dragon spring in the southern part of Norris Basin has a discharge that is difficult to estimate but is in the order of 40 gpm. Free acid, calculated as H_2SO_4 by balancing excess hydrogen ions with sulfate, is being produced at a rate of about 90 kg per day. This is far in excess of the rate of production of sulfuric acid in areas of similar size containing acid-sulfate springs, where much H_2S is oxidized to SO_3, and where the most-favored conditions appear to be: porous ground with a high ratio of particle surface area to volume, a position above the water table, temperature not far from boiling, and possibly catalytic effects of opal or other substances to foster the reaction. These conditions are represented diagrammatically in Figure 3*A* near the acid-sulfate spring, type I-4.

Frying Pan Lake in the Tarawera region of New Zealand (Grange, 1937, p. 93, 103) is probably a more striking example of the same type of water. Its rate of discharge of water has been estimated at "more than 1,000 gpm"; the discharge of free sulfuric acid is as much as 800 kg, or nearly a metric ton, per day. Porous ground of the type that appears to be most favorable for surficial oxidation of H_2S to SO_3 is of only local extent on the margins of the lake (diameter about 500 feet) and can hardly account for more than an insignificant part of the total production of sulfuric acid.

The high lithium-sodium ratio of the Green

TABLE 3.—ANALYSES OF GASES FROM AREAS OF VOLCANIC HOT SPRINGS, IN VOLUME PER CENT

	Well 4/1 Wairakei, N. Z.[1]	Well 6 Wairakei, N. Z.[2]	Steamboat Springs, Nev.[3]	Upper Basin Yellowstone[4]	Lassen Park, Calif.[5]	The Geysers, Calif.[6]	Larderello, Italy[7]
CO_2	82.73	98.06	97.23	95.10	95.05	63.50	92.17
CO			none		none		
H_2S	8.36	0.63	0.77	0.55	0.55	1.69	2.44
H_2	2.37	0.18	none	0.10	0.30	14.67	1.75
CH_4	0.11	0.12	<0.03	0.10	0.15	15.29	0.92
C_2H_6	0.39	0.05	none				
NH_3	5.36	0.06				1.28	1.71
H_3BO_3	0.03	0.007				(0.14±)	0.47
O_2			0.14	none	0.10		
H_2	0.65	0.89	1.82	4.15	3.85	3.53	0.54
A, He, Ne			0.04		0.05		0.002
Total	100.00	99.997	100.00	100.00	100.05	100.0	100.002
Gas content of steam, vol. per cent	0.04	0.51				1.94	1.06

[1] Gas in steam from well erupting sodium-chloride water, eastern part of thermal area (Wilson, 1955, p. 29).

[2] Gas in steam from well erupting sodium bicarbonate water, western part of thermal area (Wilson, 1955, p. 29).

[3] Spring 16, Main Terrace (Brannock *et al.*, 1948, p. 222). Temperature of water 94½° C.; pH 7.2.

[4] Upper Basin drill hole behind Old Faithful Inn (Allen and Day, 1935, p. 86).

[5] Pool with precipitated sulfur, Bumpass Hell (Day and Allen, 1925, p. 133, analysis 4). Temperature 84–85° C. Six miles north of Morgan Springs.

[6] Well 1 (Allen and Day, 1927, p. 60, 76). Temperature 154° C.; sample contained boric acid, "... not ... more than 20 to 40 ppm by weight" of total gases, including H_2O. A sample of completely condensed steam from well 4, collected Sept. 10, 1954, contained by partial analysis 18 ppm of H_3BO_3, and 0.13 ppm of Hg (analyst, J. O. Pera, Buckman Laboratories, Inc.). A similar sample from well 6 contained by partial analysis 13.1 ppm of H_3BO_3, 109 ppm of NH_4, and 0.5 ppm of Cl (Scott and Brannock, analysts).

[7] Average Larderello steam (Mazzoni, 1951, p. 34–35) recalculated to volume per cent. Temperatures of wells range from 140° to 230° C.

Dragon water (Table 1) is believed to indicate that most of the alkalies were derived from magma and transported in dense volcanic steam as dissolved alkali halides and were not for the most part leached from wall rocks. Unfortunately, no lithium analysis is available for Frying Pan Lake. The low content of alkaline-earth metals and of aluminum and iron, all of which are appreciably soluble at existing pH's of 2½–3, is believed to be additional evidence that these acid waters have not extensively attacked their wall rocks.

The high content of sulfate in these waters suggests that sulfur may be emitted from some magmas as oxidized sulfur gases, SO_2 and SO_3 and intermediate-valance sulfur rather than as H_2S or S, and that the acidity is caused by these oxidized gases. R. M. Garrels has suggested (Personal communication) the possibility of reactions of sulfur with water to form polybisulfides, which could in turn decompose to give sulfate and sulfide plus free acid, with decreasing temperature and pressure. On the other hand, George Kennedy (1948) has concluded that the ferric-ferrous ratio of volcanic rocks indicates low O_2 pressure and, therefore, very low SO_2 and SO_3. Are these relationships quite different in certain circumstances, perhaps related to type of magma, or is essentially all sulfur oxidized only after it leaves the magma? It is known that many volcanic fumaroles at high temperature and low pressure are very acid and contain oxidized sulfur gases (Shepherd, 1938, p. 321). When and how does the oxidation occur in fumaroles and the acid-sulfate-chloride springs?

It may be significant that geothermal gradients at Norris Basin in Yellowstone Park are very high, and with little doubt the same is true of Frying Pan Lake in New Zealand. Fenner (1936, p. 291) measured a temperature of 205°C. at Norris at a depth of only 246½ feet, which is the highest temperature that has been found at a similar depth in any explored hot spring system. No holes have been drilled at Frying Pan Lake, but the existence of very high temperatures at relatively shallow depths is indicated by the fact that volcanic eruptions occurred at the site of the lake in 1886 and 1917 (Grange, 1937, p. 93).

Burbank (1950) has presented evidence for generation of acid solutions at depth in a relatively shallow volcanic environment, and Lovering (1950) has favored acid solutions for some stages of alteration at Tintic, Utah. These solutions were apparently dense enough to transport matter of low volatility and may have been similar in nature and origin to the acid-sulfate-chloride waters here described.

The above stated lines of evidence suggest that volcanic emanations with oxidized sulfur gases and alkali halides may characterize at least some moderately shallow volcanic environments. The deep acid waters with high lithium-sodium ratios (Fig. 3*A*) may be formed by condensation of emanations that occur within a critical range of temperature and pressure. Without supporting evidence, it is suggested that optimum conditions may be provided by relatively high temperature and moderately low pressure, but with pressure still sufficiently high for the alkali halides to be appreciably soluble in a rather dense vapor; some halogen acids may also be present. The hypothesis assumes that at greater pressures and perhaps lower temperatures, sulfur is driven off as H_2S or S in vapors that form the sodium-chloride waters.

Acid-sulfate-chloride waters may also form by near-surface condensation of low-density volcanic gases containing free halogen acids. The waters of some acid crater lakes are probably of such an origin (Fig. 3*B*). The alkali metals are leached from the wall rocks. The Li/Na ratios are presumably similar to those of the wall rocks and are probably lower than in the acid-chloride waters previously discussed. This mechanism could account for the water of Frying Pan Lake; a lithium determination is needed to clarify its origin.

Sodium-Bicarbonate Waters

A little-known and relatively rare type of volcanic water is here called the sodium-bicarbonate type. Its outstanding characteristics are its low chloride and relatively high bicarbonate content; it is nearly neutral in pH. Possible modes of origin of the sodium-bicarbonate waters are illustrated in Figure 4.

A number of cold and warm waters are known to be relatively high in sodium bicarbonate, but only a few areas are definitely known to contain such waters in environments that demand a close relation to volcanism. These include the Wairakei, Waiotapu, and Rotorua areas of New Zealand (James Healy, personal communication), and Steamboat Springs, Nevada. At Wairakei and Steamboat, the sodium-bicarbonate waters are found only in wells; several springs of this type have been found associated with sodium-chloride water at Waiotapu and Rotorua. The writer suspects that volcanic sodium-bicarbonate water nor-

mally occurs below the zone of easy access of air and is present in some areas where it has not been suspected. With surficial oxidation of associated H_2S, the sodium-bicarbonate waters may change to acid-sulfate waters.

The existence of the volcanic sodium-bicarbonate type was first demonstrated in the western part of the Wairakei area, New Zealand (Healy, 1953; Wilson, 1955, p. 37; *see* analyses of well 5, Table 1, and well 6, Table 3). Healy and Wilson suggest that steam with CO_2 has separated from sodium-chloride water at depth (at least 1000 feet) and at some higher level is condensed in meteoric water, perhaps as in Figure 4*C*. Dissolved CO_2 reacts with the wall rocks; at high temperatures calcium and magnesium carbonates are only slightly soluble, potassium is commonly fixed in clay minerals and feldspars, and sodium bicarbonate becomes the dominant component of the dissolved solids.

In the central and eastern parts of the explored Wairakei area, normal sodium-chloride water (*see* analyses of well 4, Tables 1, 3) rises to high levels and is locally discharged in springs. One well (No. 7) must have been near the contact between these two distinctly differing sodium-bicarbonate water, and adularia with minor albite is typical of a major deep zone of alteration in the central and eastern area, containing sodium-chloride water (Steiner, 1953; 1955). Adularia has also been found with the sodium-chloride waters of Steamboat Springs and the Upper Basin of Yellowstone Park, but hydrothermal albite is rare or absent in other explored hot spring systems (White, 1955, p. 104). Is hydrothermal albite closely related to the sodium-bicarbonate waters, and adularia to sodium-chloride waters?

A dilute sodium-bicarbonate water was found at depth in the western part of the Steamboat Springs thermal area. The drill hole apparently went through a zone of this water and into saturated steam mixed with CO_2 and H_2S that apparently rises into and is condensed by the overlying water. Although the bottom of

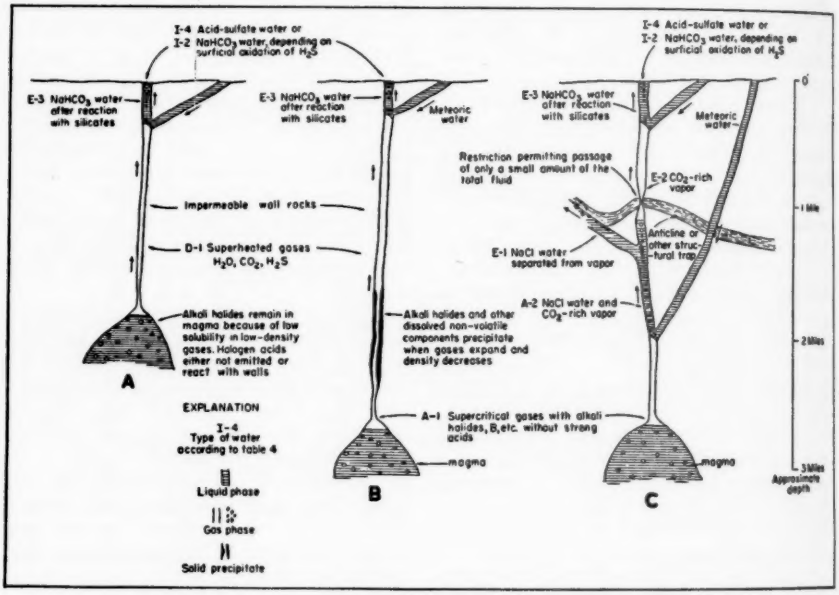
I-4 Acid-sulfate water or
I-2 NaHCO3 water, depending on surficial oxidation of H2S
E-3 NaHCO3 water after reaction with silicates
Meteoric water
Impermeable wall rocks
D-1 Superheated gases H2O, CO2, H2S
Alkali halides remain in magma because of low solubility in low-density gases. Halogen acids either not emitted or react with walls
A
Restriction permitting passage of only a small amount of the total fluid
E-2 CO2-rich vapor
Anticline or other structural trap
E-1 NaCl water separated from vapor
A-2 NaCl water and CO2-rich vapor
Alkali halides and other dissolved non-volatile components precipitate when gases expand and density decreases
A-1 Supercritical gases with alkali halides, B, etc. without strong acids
magma
B
C
0
1 Mile
2 Miles
3 Miles Approximate depth
EXPLANATION
I-4
Type of water according to table 4
Liquid phase
Gas phase
Solid precipitate

FIGURE 4.—SUGGESTED GENESIS OF VOLCANIC SODIUM-BICARBONATE WATERS BY THREE POSSIBLE MECHANISMS

Depending on depth of penetration of meteoric water and density of gas phase. Widths of fissures greatly exaggerated.

the drill hole is at a lower altitude than the water table of sodium-chloride water to the east, chloride water is completely absent.

James Healy has suggested (Personal communication) that a CO_2-rich vapor phase can separate from sodium-chloride water that is flowing with a strong horizontal component; the vapor phase can later dissolve at higher levels in ordinary ground water heated by conduction and the vapor. Reactions with the containing rocks can then form sodium-bicarbonate water. He has pointed out that principles suggested by Hubbert (1953) for separating gas, oil, and water are also applicable to thermal systems.

Springs that are probably equivalent to sodium-bicarbonate water have been found at "The Geysers" in California (Allen and Day, 1927, p. 33). Steam containing CO_2, H_2S, and other gases (Table 3) apparently rises into near-surface meteoric water and is condensed. CO_2 reacts with the wall rocks and dissolves alkali and alkaline-earth metals as bicarbonates. Because of the facts that alkali-rich rocks are scarce, serpentine is abundant in the wall rocks and temperatures of some of the springs are low enough for appreciable solubility of calcium and magnesium bicarbonates, sodium is the dominant metallic ion in only one of the springs (Allen and Day, 1927, p. 33). In spite of their differences, all the volcanic bicarbonate waters are included for present purposes in the sodium-bicarbonate type although other subdivisions may be desired in the future. Most of the other springs of "The Geysers" area are of the acid-sulfate type, discussed below. Surficial oxidation of H_2S to sulfuric acid has probably changed some sodium-bicarbonate waters to the acid-sulfate type.

C. J. Banwell of the New Zealand Physical Laboratory and the writer made a series of temperature measurements on December 6, 1955, in a new steam well drilled to a depth of 600 feet at "The Geysers" late in October 1955. The well contained steam that was apparently saturated (wet) for the casing-head pressure to a depth of about 300 feet, and temperatures were near 160°C. Temperatures were determined by a geothermograph supplied by the New Zealand government, of the type described by Banwell (1955, p. 64–66). Total casing-head pressures ranged from 86 lbs./sq. in. at the start of the measurements to 97 lbs./sq. in. when the geothermograph was at 300 feet. From 350 to 450 feet the temperature rose to 178° C., and this temperature was maintained to the bottom of the hole. The final total casing-head pressure was 104 lbs. per sq. in.; steam in the lower part of the well was superheated by about 12° C. The presence of wet steam to a depth of 300 feet, and of zeolites and other hydrothermal minerals in altered rocks erupted from the well are evidence that, before drilling, there was a liquid phase in much of the upper part of the spring system. Where H_2S was not abundantly oxidized, this liquid phase was probably a sodium-bicarbonate type of water.

The thermal system of "The Geysers" is illustrated by Figure 4, type A or B. No trace of sodium-chloride water has been found, and none of the analyzed hot springs (Allen and Day, 1927, p. 33) contain more than 1.8 ppm of chloride. To test the possibility that unseen sodium-chloride water might be escaping into Sulphur Creek, water samples were taken immediately above the springs as well as near the Cloverdale quicksilver mine 4 miles below the springs. Both samples contained only 2 ppm of chloride, proving that no unseen sodium-chloride water is discharging near by from the system, and no possibility is known within a 10-mile radius of the area.

There is also no published evidence to suggest that sodium-chloride waters occur in the Larderello, Italy, thermal areas, where superheated steam is utilized to produce an important part of Italy's electric power (Mazzoni, 1951). Sodium-chloride water seems to be absent both here and at "The Geysers." Meteoric water probably mixes at such shallow depths and low pressures that the volcanic steam has not condensed at sufficiently high density to retain the alkali halides in solution. The latter may have precipitated from the vapor phase above the magma (Fig. 4*B*), as temperature and density of the vapor decreased, or pressure on the magma chamber may have been so low that no halogens were evolved in combination with alkali metals (Fig. 4*A*).

Acid-Sulfate Waters

The characteristics of acid-sulfate waters have been described by Allen and Day (1935, p. 65, 100–125, 393–448), who called them "acid waters", and briefly by White, Sandberg, and Brannock (1953, p. 493), and others. The waters contain relatively high sulfate and low chloride, and the pH is low (generally from 2 to 5). The near absence of chloride distinguishes these waters from the acid-sulfate-chloride type. An example from Norris Basin is shown in Table 1. Springs of this type are generally situated on relatively high ground, and discharges

are meager in comparison to typical sodium-chloride springs. Allen and Day believed that this type of water owes its origin to a shallow circulation of meteoric water, presumably because of lack of adequate supply or low permeability of the bed rocks. This permits superheated steam from a magma to approach nearly to the surface. Alkali halides, and other low-volatile components are either retained in the magma or are precipitated at depth as the steam expands and decreases in density (Fig, 4*A*, 4*B*). Steam that condenses near the surface becomes acid if associated H_2S is oxidized. The present writer agrees with Allen and Day that the mechanisms illustrated in Figures 4*A* and 4*B* are the best explanations for acid-sulfate springs not closely associated with chloride waters, as at "The Geysers", Larderello, and probably some thermal areas in Yellowstone and Lassen Parks and elsewhere.

Other acid-sulfate springs, however, are closely associated with or are surrounded by sodium-chloride waters (Allen and Day, 1935, p. 72). The writer believes that they result from steam that has boiled from chloride water at depth and has condensed again near the surface, and is then acidified by oxidizing H_2S (*see* type I-4 waters in Figs. 2*A*, 3, 4*C*). Where condensation occurs below the zone of extensive oxidation, sodium-bicarbonate water can first form and later be acidified near the surface. Some acid-sulfate springs are completely surrounded and underlain by sodium-chloride water in an environment that clearly points to direct boiling-off of steam and other gases, followed by condensation and acidification. An example was found by the writer on the Main Terrace at Steamboat Springs (spring 14). The terrace has been penetrated by 5 drill holes, all entering the chloride water table a few feet below the surface. The spring is a pure acid-sulfate type when the water level in its feeding fissure is 1 foot or more below the surface. When the water level rises, the spring changes gradually to the acid-sulfate-chloride type and eventually to nearly neutral sodium-chloride water. Other examples are known in the Upper Basin of Yellowstone Park and Beowawe Geysers in Nevada.

The compositions of the acid-sulfate springs are clearly related to the rocks that bound the spring pools. Iron, aluminum, calcium, and magnesium are abundant in the more acid springs if the wall rocks contain appreciable quantities of these metals. From the few available analyses, the Li/Na ratios of the acid-sulfate springs are considerably lower than those of the sodium-chloride springs (Table 1). The alkalies of the former are dissolved from the wall rocks in approximate proportion to abundance. There is no evidence for selective leaching of lithium relative to the other alkali metals.

Calcium Bicarbonate Waters

The compositions of all types of volcanic waters are influenced to some extent by reactions with wall rocks. This has been stated or implied in the previous discussion. When sodium-chloride waters come in contact with silicate rocks at high temperatures, sodium is typically enriched in the water by rock alteration as potassium is removed; some additional sodium is dissolved by reactions involving CO_2; the pH progressively increases (if all CO_2 is dissolved in the liquid phase without a reservoir in a vapor phase); and little Ca, Mg, Fe, and Al dissolve because of low solubilities at high temperature or because the waters are nearly neutral and contain H_2S.

In contrast to the above, the calcium-bicarbonate type of water is believed to form when sodium-chloride water is sufficiently cooled (Fig. 5) so that calcium bicarbonate is soluble in relatively large amounts (Garrels and Dreyer, 1952, p. 339–340; Miller, 1952, p. 175). This implies that sodium-chloride water can come into contact with limestone at 200°–300° C. with little change in composition, although solution and redeposition of calcite may occur. At temperatures near 100° C., sodium-chloride waters do not contain more than 20 ppm of calcium except when combined CO_2 is particularly low. The available solubility data for calcium carbonate at temperatures close to that of the Mammoth hot springs (Garrels and Dreyer, 1952, p. 339, 340; Miller, 1952, p. 175, 178) suggests that these springs, with 260 ppm of Ca and 500 ppm of HCO_3 (Table 1), are essentially saturated with calcium carbonate. Their subsurface temperatures have probably not been much higher than their vent temperatures. This is consistent with the writer's observations that calcium-bicarbonate springs seldom if ever emerge at boiling temperatures, and that discharging water starts to precipitate carbonate at or very near the spring vents. This type of water probably forms only when volcanic sodium-chloride water is so greatly diluted by cold meteoric water that the mixing temperature is in the order of 100° C. or less; if the mixture contains dissolved CO_2, and comes in contact with limestone for a sufficient time, it changes to the calcium-bicarbonate type by dis-

solving $CaCO_3$. The content of calcium bicarbonate of thermal waters may be useful as a crude geothermometer, indicating the maximum temperature the water has had since coming in contact with a supply of calcium carbonate.

by temperature and pressure of the environment in which the author believes them to occur. Degree and depth of mixture with meteoric water, depth and temperature of source intrusions, and reactions with different types of wall rocks are considered to some extent. A

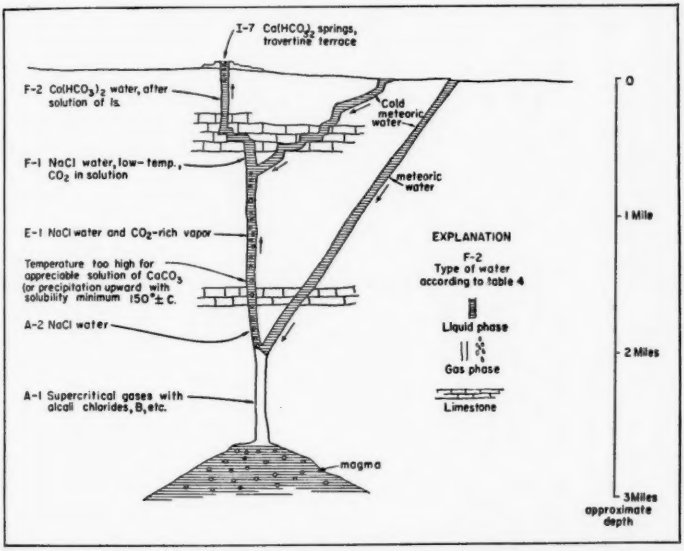
I-7 $Ca(HCO_3)_2$ springs, travertine terrace
F-2 $Ca(HCO_3)_2$ water, after solution of ls.
Cold meteoric water
F-1 NaCl water, low-temp., CO_2 in solution
meteoric water
E-1 NaCl water and CO_2-rich vapor
EXPLANATION
F-2
Type of water according to table 4
Temperature too high for appreciable solution of $CaCO_3$ (or precipitation upward with solubility minimum 150°± C.
Liquid phase
Gas phase
Limestone
A-2 NaCl water
A-1 Supercritical gases with alcali chlorides, B, etc.
magma
0
1 Mile
2 Miles
3 Miles approximate depth

FIGURE 5.—SUGGESTED GENESIS OF VOLCANIC CALCIUM-BICARBONATE WATER
Widths of fissures greatly exaggerated.

In contrast to the above, volcanic sodium-chloride springs seem to be unsaturated with calcium carbonate at vent temperatures, except where the pH also rises greatly in geysers and spouting springs with loss of CO_2 (White, Sandberg, and Brannock, 1953, p. 496–498). At Steamboat Springs, calcite is absent in veins and altered rocks from the surface to depths of about 150 feet but is relatively abundant at greater depths (White, 1955, p. 112). George Kennedy has suggested to the writer (Personal communication) that the solubility of calcium carbonate attains a minimum at a temperature somewhat above 100° C. The Steamboat data are consistent with this hypothesis and suggest that the minimum for water of Steamboat's composition and CO_2 content is about 150° C.

OUTLINE OF POSSIBLE MODES OF ORIGIN OF THE MAJOR TYPES OF VOLCANIC WATERS

The types of water previously discussed by composition and origin are arranged in Table 4 wide variety of compositions and of histories are apparent. This table is not intended to be a complete outline of the possibilities, because our knowledge of the processes is much too inadequate.

Most of the waters are believed to be directly or indirectly related to dense volcanic vapors containing alkali halides in solution. The direct condensation of such a vapor is believed to yield the volcanic sodium-chloride waters. Most other waters are evolved from the latter; the exceptions appaer to be related to low-density superheated vapors that contain little matter of low volatility.

Specific ranges for temperatures are not stated but are in the general order of: low temperature <100° to 150°± C.; intermediate temperature 150°± to 370°± C.; high temperature >370°C.

In groups A, E, and I, pressures are near those of saturated steam for the existing temperatures. In groups D and H, pressures are slightly lower than for saturated steam, and

TABLE 4.—SUGGESTED ENVIRONMENTAL RELATIONSHIPS OF THE MAJOR TYPES OF VOLCANIC WATERS*

Degree and depth of mixture with meteoric water, reactions with wall rocks, and depth of source intrusions are also involved. The list does not include all possibilities. Evolution of many are illustrated in Figures 2–5.

	High pressure	Intermediate pressure	Low pressure
High temperature	A. High P-high T 1. Dense volcanic steam—H_2S, alkali halides, B, SiO_2 *etc.* from moderately deep intrusion(?).† (Figs. 2*A*, 4*B*, 4*C*, 5) 2. NaCl water—A-1 condensed in deep meteoric water; associated CO_2-rich vapor.† (Figs. 2*A*, 4*C*, 5) 3. Moderately dense volcanic steam, very high temp. from local intrusion; alkali halides, SO_3, SO_2, possibly halogen acids. (Fig. 3*A*) 4. Acid-sulfate-chloride water from condensation of A-3; CO_2-rich vapor phase. (Fig 3*A*)	D. Intermediate P-high T 1. Superheated vapor from moderate depth intrusion or from sufficient expansion of A-1 to precipitate low-volatile components; CO_2, H_2S. (Fig. 4*A*, *B*) 2. Superheated vapor with SO_2, SO_3, possibly halogen-acid gases from moderate-depth intrusions, or from A-3 with precipitation of nonvolatiles.† (Figs. 2*B*, 3*B*)	G. Low P-high T 1. Superheated fumaroles with CO_2, H_2S, from D-1. 2. Superheated fumaroles with halogen acids, SO_2, SO_3, from D-2 or from lavas and shallow intrusions.† (Fig. 3*B*)
Intermediate temperature	B. High P-intermediate T 1. NaCl water, from enough cooling of A-2 by conduction or meteoric water to dissolve vapor phase with CO_2.† (Fig. 2A) 2. Acid-sulfate-chloride water from further cooling of A-4; may have a CO_2-rich vapor phase, insoluble because of acidity.	E. Intermediate P and T 1. NaCl water from A-2; from B-1 with little cooling; from A-4 or B-2 by neutralization; CO_2-rich vapor phase.† (Figs. 2*A*, 4*C*, 5) 2. CO_2-rich vapor, separated physically from A-2 or E-1. (Fig. 4*C*) 3. $NaHCO_3$ water from condensation of D-1 or E-2, then reaction with silicate wall rocks. (Figs. 4*A*, *B*, *C*) 4. Acid-sulfate-chloride water from A-4 or B-2; high in Li. (Fig. 3*A*) 5. Acid-sulfate-chloride water by condensation of D-2 and reaction with wall rocks; low in Li. (Fig. 2*B*)	H. Low P-intermediate T 1. Superheated H_2O-CO_2-H_2S vapors from D-1, E-2, E-4, or G-1. 2. Superheated vapors with strong acid-forming components from D-2 or G-2.† (Fig. 3*B*)

		5. Acid-sulfate-chloride water by condensation of D-2 and reaction with wall rocks; low in Li. (Fig. 2*B*)	
Low temperature	C. High P-low T 1. NaCl water by sufficient cooling of B-1. 2. $Ca(HCO_3)_2$ water by reaction of C-1 with limestone.	F. Intermediate P-low T 1. NaCl water from C-1, or sufficient cooling of B-1 or E-1; no vapor phase.† (Fig. 5) 2. $Ca(HCO_3)_2$ water from C-2 or from F-1 reacting with limestone.† (Fig. 5)	I. Low P-low T 1. NaCl water from E-1, E-4 (by reaction) or F-1; may have CO_2-rich vapor phase; high in Li.† (Fig. 2*A*) 2. $NaHCO_3$ water, from E-3 or condensation of H-1 and reaction. (Figs. 4*A*, *B*, *C*) 3. Steam with CO_2, H_2S, from Group E or from H-1 or I-1, separating above water table.† (Figs. 2*A*, 3*A*) 4. Acid-sulfate water from partial condensation I-3, and oxidation of H_2S; also by oxidation of H_2S in I-2.† (Figs. 2*A*, 3*A*, 4*A*, *B*, *C*) 5. Acid-sulfate-chloride water from oxidation of H_2S in I-1; high in Li. (Figs. 2*A*, 3*A*) 6. Acid-sulfate-chloride water from surficial condensation of G-2 or H-2; low in Li. (Fig. 3*B*) 7. $Ca(HCO_3)_2$ water from F-2. (Fig. 5) 8. NaCl water from neutralization of E-5 or I-6; low in Li.† (Fig. 2*B*)

* Assumptions for Table 4.

1. Alkali halides are appreciably soluble in superheated steam near and above the critical pressure of water.
2. Sulfur is generally emitted from the magma as H_2S or S. In certain little-understood conditions, perhaps where temperature is high relative to pressure, much sulfur may be emitted as SO_2 or SO_3 (*See* text).
3. Liquid phase of all types of water reacts with wall rocks, at least to some extent; the same presumably holds for high-density vapors.
4. Alkaline-earth metals are only slightly soluble in CO_2-bearing waters at high temperatures but become appreciably soluble at temperatures below 100°C. (*See* text).

† Probably relatively abundant.

group G is highly superheated. Pressures in groups B and F are somewhat higher than saturation pressures and are very high relative to temperature in group C.

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U. S. Geological Survey, Menlo Park, Calif.
Manuscript Received by the Secretary of the Society, March 26, 1957
Publication Authorized by the Director, U. S. Geological Survey

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 68, PP. 1659–1682, 1 FIG. DECEMBER 1957

MAGMATIC, CONNATE, AND METAMORPHIC WATERS

BY DONALD E. WHITE

ABSTRACT

Some major types of water of "deep" origin are believed to be recognizable from their chemical and isotopic compositions. Oil-field brines dominated by sodium and calcium chlorides differ markedly from average ocean water. In general, the brines are believed to be connate in origin ("fossil" sea water) with a negligible to high proportion of meteoric water. Many brines, particularly in pre-Tertiary rocks, are much higher in salinity than sea water and are greatly enriched in calcium as well as sodium chloride. Brines near the salinity of sea water are generally higher, relative to sea water, in bicarbonate, iodine, boron, lithium, silica, ammonium, and water-soluble organic compounds, and lower in sulfate, potassium, and magnesium.

Many changes take place after sea water is entrapped in newly deposited marine sediments: (1) Iodine, silicon, boron, nitrogen, and other elements have been selectively concentrated in organisms that decompose during and after burial in sediments. Many of the elements may redissolve in the interstitial water. (2) Bacteria are active in the sediments and reduce sulfate to sulfide and produce methane, ammonia, carbon dioxide, and other products. (3) Some elements have been selectively removed from sea water by inorganic processes, such as adsorption on clays and colloidal matter. When this matter is reconstituted by diagenetic and other changes, some components are redissolved. The abundance of lithium and possibly boron and other elements may be controlled to a considerable extent by these inorganic processes. (4) The interstitial water may react chemically with enclosing sediments and produce dolomite, reconstituted clays, and other minerals. The high loss of magnesium relative to calcium in most connate waters is probably caused by such reactions.

Volcanic hot-spring waters of different compositions have been discussed in an accompanying paper (White, 1957). The most significant type is believed to be dominated by sodium chloride, and is best explained as originating from dense gases driven at high temperature and pressure from magma and containing much matter of low volatility that is in solution because of the solvent properties of high-density steam. This dense vapor is condensed in and greatly diluted by deeply circulating meteoric water. Most other types of volcanic water are believed to be derived from the sodium-chloride type.

Volcanic sodium-chloride waters are similar in many respects to connate waters but are believed to be distinguishable by relatively high lithium, fluorine, silica, boron, sulfur, CO_2, arsenic, and antimony; by relatively low calcium and magnesium; and by lack of hydrocarbons, water-soluble organic compounds, and perhaps ammonia and nitrate. Relatively high boron and combined CO_2 are alone not reliable indicators of a volcanic origin.

During compaction, rocks lose most of their interstitial high-chloride water; much additional water may then be lost during progressive metamorphism, and the content changes from about 5 per cent in shale to perhaps 1 per cent in gneiss. This expelled water is here called metamorphic. Because of pressure and permeability gradients, it must normally escape upward and mix with connate and meteoric water. Even though large quantities must exist, no example of metamorphic water has been positively identified.

Some thermal springs in California are high in salinity and relatively low in temperature and apparent associated heat flow. Some are clearly connate in origin. Other springs are characterized by very high combined carbon dioxide and boron, relative to chloride. Their compositions are considerably different from known connate and volcanic waters and are believed to be best explained by a metamorphic origin.

Although some major types of deep water seem to be recognizable, there is much danger of oversimplifying the problems. Many waters are no doubt mixtures of different types, and some of high salinity result from dissolution of salts by meteoric water.

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Introduction

Statement of the Problem

Many thermal springs occur in areas of recent or active volcanism, are high in temperature and in associated total heat flow, and have chemical characteristics that indicate a close relation to volcanism (White, 1957). Other springs have only low to moderate temperatures but are more highly mineralized than ordinary ground waters. Do some of these springs also contain volcanic water, or is the mineral matter derived from nonvolcanic sources? This is part of a broader problem: How many different genetic types of ground water exist, and what means are available to distinguish each from the others?

When fine-grained marine sediments are deposited, their initial water content is commonly 50 per cent or more of the wet weight (Emery and Rittenberg, 1952, p. 747–755). Most of this water is driven off during compaction and progressive metamorphism. Clarke (1924, p. 631) computed the average water content for the following rocks: Shale, 5.0 per cent; slate, 3.8; and schist, 2.0. No averages are given for gneiss, but individual analyses (p. 630) range from 0.4 to 1.8 per cent. For comparison, average granodiorite, which is at least in part ultrametamorphosed or fused sedimentary rock, contains only 0.65 per cent of water (Nockolds, 1954, p. 1014). The evidence is clear that very large quantities of connate and metamorphic water must be driven off from sediments during compaction, progressive metamorphism, and reconstitution to minerals containing little water. Some of this water no doubt reaches the surface in thermal springs.

Some effort has been made in the past to distinguish ocean water from oil-field brines (Revelle, 1941; Vinogradov, 1948; Piper *et al.* 1953, p. 90–92). The characteristics of volcanic or magmatic water as compared with the waters driven from sediments are much less well known.

The writer has considered magmatic or volcanic waters of different types in an associated paper (White, 1957) and concluded that the sodium-chloride type is derived directly from high-density vapors at considerable depth and is most representative of magmatic emanations. Other types seem to be for the most part derived from the sodium-chloride type. The

volcanic sodium-chloride waters are here compared with ocean water and with other possible types of "deep" water.

This paper reviews the characteristics of different kinds of "deep" water, within the limitations of available data. Analyses containing many of the components now believed to be diagnostic are surprisingly scarce. The most diagnostic components seem to be: all the halogen and alkali elements; all the ionic and molecular species of sulfur, carbon, boron, and nitrogen; silica; organic compounds; and isotopes of the water. The alkaline-earth elements and many other metals are of considerable interest but are of less diagnostic value because quantities in natural solutions are so dependent on pH or other components in the water. The more soluble components that rarely attain saturation are particularly significant.

The writer wishes to emphasize the tentative nature of the conclusions reached here. Additional data will surely change some of these conclusions but others, it is hoped, will become established criteria for distinguishing different types of water.

Acknowledgments

The writer is greatly indebted to many individuals for stimulating conversations and ideas that have led to the writing of this paper. Of initially great value was the published account of Wilbur Springs, California by G. A. Waring (1915, p. 99–103) that brought to the writer's attention the anomalously low temperature, high salinity, and high iodine content of these springs. These characteristics suggested a nonvolcanic origin, and are now interpreted to indicate connate water. Mr. Waring has also assisted in some of the bibliographic study for the present work.

Mr. Cole R. McClure of the California Division of Water Resources has been very helpful in discussing the characteristics of oil-field brines and in making available a number of brine analyses, of which the Rio Vista sample of Table 1 is typical. Data on the stable isotopes of some of the waters have been provided by Dr. Harmon Craig of the University of Chicago and Scripps Institution of Oceanography, and on tritium by Dr. Fred Begemann of the University of Chicago. Some of the problems have been discussed most helpfully with Dr. E. G. Zies of the Geophysical Laboratory. The writer is greatly indebted to his associates on the U. S. Geological Survey, especially to H. L. James, V. E. McKelvey, Edgar H. Bailey, P. F. Fix, S. Muessig, and C. H. Sandberg, who have read the manuscript. A. H. Lachenbruch of the Geological Survey has been most helpful with considerations of heat flow of the different types of thermal springs. Much benefit has also been derived from discussions and communications with the following members of the U. S. Geological Survey: C. S. Howard, V. T. Stringfield, H. E. LeGrand, S. K. Love, W. F. White, C. L. McGuinness, J. H. Feth, J. D. Hem, and F. H. Rainwater. None of these men, however, should be held responsible for interpretations and conclusions.

Definitions

Terms defined elsewhere.—The following terms were defined in an accompanying paper (White, 1957): thermal spring, hydrothermal, magmatic water, plutonic water, volcanic water, and mixed water. Other definitions that apply particularly to the present paper are:

Meteoric water.—Meteoric water, according to Lane (1908) includes connate water as well as "rain, vadose, or pluvial waters". As used here, the term meteoric applies to water that was recently involved in atmospheric circulation. The age of meteoric ground water is slight when compared with the age of the enclosing rocks and is not more than a small part of a geologic period. The writer's usage is very similar to that of Meinzer (1923, p. 31) except that age is specifically considered.

Connate or fossil water.—Connate water, as the term is used in the present paper, is "fossil" water that has been out of contact with the atmosphere for at least an appreciable part of a geologic period. It consists of the fossil interstitial water of unmetamorphosed sediments and extrusive volcanic rocks and water that has been driven from the rocks. The term has been defined and redefined a number of times since it was first proposed by Lane (1908, p. 502–507; *see* Rogers, 1917, p. 20–21; Meinzer, 1923 p. 31; Case, 1955). Lane clearly recognized that some brines consist of mixtures of connate and meteoric water, and that some connate water may have been nonmarine. Much of the confusion stems from Lane's implication, followed by Meinzer (1923, p. 31) that connate water has remained since burial with the rocks in which it occurs. This is an unworkable restriction that probably never holds in detail (*see* for example, Emery and Rittenberg, 1952, p. 751–763) and should be abandoned. For those who insist that the term connate should be retained solely for waters "born with" the

immediately enclosing rocks, the term fossil water is suggested.

Another major source of confusion stems from the fact that no oil-field brine is identical in composition to sea water. The drastic changes that occur in sea water after burial have been reviewed by Emery and Rittenberg (1952), and by Schoeller (1956) and are a major part of the present study; in general, the changes are believed to result from normal reactions of water with sediments and associated organic matter, induced in considerable part by bacterial action and also influenced by elevated temperature and time. "Formation water", defined as the water present in rocks immediately before drilling (Case, 1955), may be a useful nongenetic term for waters of unknown age and origin but should not replace the genetic concept of connate or fossil water.

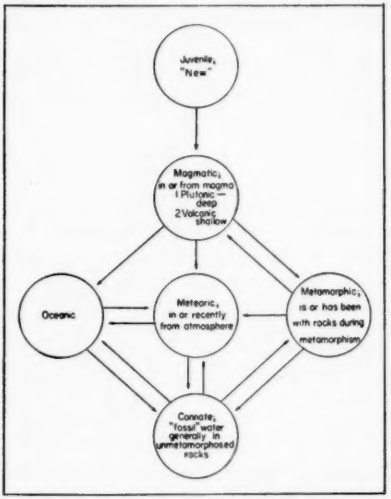
Juvenile, "New"
Magmatic, in or from magma
1 Plutonic — deep
2 Volcanic, shallow
Oceanic
Meteoric, in or recently from atmosphere
Metamorphic, is or has been with rocks during metamorphism
Connate; "fossil" water generally in unmetamorphosed rocks

FIGURE 1.—SIMPLIFIED DIAGRAM ILLUSTRATING THE RELATIONSHIPS OF GENETIC TYPES OF WATER CONSIDERED IN THIS PAPER

Chebotarev (1955) and others have held that all oil-field brines are entirely meteoric water that has circulated deeply and dissolved mineral matter. A little isotope evidence is already available to indicate that the D/H ratios of oil-field brines is significantly higher than in most surface waters (Rankama, 1954, p. 155, 157–159). Additional unpublished measurements on the isotopes of oxygen as well as hydrogen (Harmon Craig, personal communication) indicate that oil-field brines are derived from ocean water and are unlike most meteoric waters.

Metamorphic water.—Metamorphic water as here defined is water that is or that has been associated with rocks during their metamorphism. Meinzer (1923, p. 31) had a somewhat similar concept termed water of dehydration. Metamorphic water is probably derived largely from hydrous minerals during recrystallization to anhydrous minerals. In its broadest sense, connate or fossil water could also include metamorphic water, because water of hydration of minerals of sedimentary rocks was at one time involved in atmospheric circulation. In the process of recrystallization, however, some, if not most, oxygen atoms were exchanged for the oxygen atoms of silicate materials; on an atomic scale, identity is not maintained. As used here, connate water is considered to consist largely of water that was interstitial and was driven off before metamorphism. It presumably grades into metamorphic water, just as sedimentary rocks grade into metamorphic rocks.

Juvenile water.—"New" water that is in, or is derived from, primary magma or other matter and has not previously been a part of the hydrosphere. Volcanic or magmatic waters (for definitions, *see* White 1957) are not assumed to be juvenile unless indicated by significant evidence.

COMPARISON OF OCEAN, CONNATE, AND VOLCANIC WATERS

Method of Approach

Relationships of the types of water defined here or in the previous paper (White, 1957) are illustrated diagrammatically in Figure 1. Only the oceanic, meteoric, and one type of magmatic water can be sampled and identified with certainty.

The existence of connate water has been questioned by Chebotarev (1955) and others, but these skeptics have not explained satisfactorily how all the original interstitial water of marine sediments was flushed from deeply buried rocks or why so much highly soluble matter was retained; they have also failed to explain the detailed chemical and isotopic composition of the interstitial water.

Most geologists will grant that oil-field brines probably contain some "fossil" connate water of an age that is not greatly different from that of the enclosing rocks. Many oil-field waters, on the other hand, contain little di-

solved matter (Crawford, 1940; 1942; 1949); they are probably for the most part meteoric, most of the original connate water having been flushed out.

Other oil-field waters have 5–10 times the salinity of present ocean water and are also characterized by very high calcium as well as sodium chlorides. Their origin has long been debated (Mills and Wells, 1919; Russell, 1933; De Sitter, 1947; Chebotarev, 1955) and cannot be discussed in detail here. Most geologists have favored some process of subsurface concentration to account for their compositions. These high-density brines are relatively abundant and are generally in pre-Tertiary rocks; they are generally not associated with salt beds or unconformities; and they show remarkable similarities in chemical composition over large areas (Hoskins, 1947; Jeffords, 1948; Meents *et al.*, 1952; and De Sitter, 1947, p. 2033–2034). These characteristics point strongly to a connate origin; salts were concentrated by processes that are not yet well understood but which involve selective removal of water.

For comparison with other waters, oil-field brines dominated by chloride have been selected as the most likely representatives of connate waters or simple dilutions of such waters (Table 1). Chebotarev (1955, p. 153) has stated that oil-field waters dominated by sulfate occur at a mean depth of 1800 feet, by bicarbonate, at a depth of 2300 feet, and by chloride, at 3500 feet. The chloride waters are therefore more likely to be connate water or simple dilutions of such waters.

Selected analyses of volcanic hot springs of the sodium-chloride type are shown in Table 2. Of the different types of water in volcanic association, the sodium chloride type is held to be most representative of deep volcanic water (White, 1957).

The writer's approach in comparing selected waters that are most likely to contain the desired deep types, and his objectives, are different from Schoeller's, who has recently completed an outstanding monograph (1956) comparing oil-field waters with ordinary ground and mineral waters. Schoeller's main purpose was to bring out chemical contrasts between oil-field waters and other waters not associated with petroleum. In Schoeller's statistical treatment, all oil-field waters of varied chemical type, complexity of history and likely content of connate water, are considered together and are compared with the nonpetroliferous waters. Some of the latter are probably entirely meteoric, but others, judging from the present study, contain connate and perhaps metamorphic water. Schoeller's study and this one overlap in part; where conclusions are in apparent disagreement, the cause is likely to be found in the differences in scope and treatment of the data.

No metamorphic water has yet been identified with certainty, but in a later section of this paper evidence is presented to show that some thermal springs are probably of connate and metamorphic origin.

No way is yet known to distinguish between juvenile and recycled magmatic water. This paper also does not treat in detail criteria to distinguish the different "deep" waters from meteoric water that has come in contact with salt beds. It is hoped that this can be done adequately when more chemical and isotopic data are available.

To orient the reader, the tentative criteria that are concluded to distinguish major types of ground water of different origins are summarized in Table 3. The known ranges in chemical components of ocean, oil-field, and volcanic waters of the chloride types are shown in Table 4.

Each characteristic or chemical component is discussed in turn for the oceanic, connate, and volcanic waters. The physical and geochemical reasons for the differences are thus more apparent than if summarized separately for each type of water.

Temperature and Heat Flow

The temperatures of oil-field brines in situ are largely dependent upon depth below the surface. Temperature gradients in sedimentary basins are generally in the order of 1°C. per 150 feet of depth, and the rate of flow of heat to the surface is approximately 1.2×10^{-6} cal./sq. cm/sec. (Birch, 1954, p. 645). When connate brines from depth escape rapidly along faults or other permeable aquifers, they should have temperatures that are considerably above "normal" for their new environment. Some warm springs that are believed to have such an origin are discussed later.

Temperatures and heat flow associated with volcanic hot springs are commonly very high. (Table 2; White, 1957).

Isotopes of the Waters

The isotopic compositions of hot spring waters will be discussed in detail in papers by

TABLE 1.—ANALYSES OF OIL-FIELD BRINES OF THE CHLORIDE TYPES, COMPARED WITH OCEAN WATER

(In parts per million)

	Ocean[1]	Huntington Beach, Orange Co., California[2]	Rio Vista Field, Solano Co., California[3]	Seaboard Field, Fresno Co., California[4]	Elliott Co., Kentucky[5]	Oil test, Colusa Co., California[6]
Temp. °C.		>50				21.3
pH			7.3	6.4		7.2
SiO_2	7	90	30	36		13
Fe	0.02	0.79			0.52	
Al	1.9					
Ca	400	177	98	2190	12,300	590
Mg	1270	127	3.4	832	3350	90
Ba	0.05	24		42		
Sr	13	2.6			628	130
Na	10,600	9400	3770	14,800	40,200	6100
K	380	124	50	251	191	61
Li	0.1		2.0			2.7
NH_4	0.05	(160)	25	31		40
As	0.017					
CO_3		0	0	0		0
HCO_3	140	1500	1760	193	28	60
SO_4	2650	1.0	5.9	0.0	66	
Cl	19,000	14,400	4960	29,000	93,900	11,000
F	1.4	0.6	1.8	0.6		
Br	65	99	16	108	817	
I	0.05	35	17	21	10	
NO_3	0.7		3.3	44		
NO_2	0.05			0.0		
B	4.6		108	8.3		20
Sum	34,500	26,100	10,900	47,600	151,000	18,100
Ratios by wt.						
HCO_3/Cl	0.0074	0.10	0.35	0.0067	0.00030	0.0055
SO_4/Cl	0.14	0.00007	0.0012	0.00000	0.0007	
F/Cl	0.00007	0.00004	0.00036	0.00002		
Br/Cl	0.0034	0.0069	0.0032	0.0037	0.0087	
I/Cl	0.000003	0.0024	0.0034	0.00072	0.00011	
B/Cl	0.00024		0.022	0.00029		0.0018
K/Na	0.036	0.013	0.013	0.017	0.0048	0.010
Li/Na	0.00001		0.00053			0.00044
Ca + Mg/Na + K	0.15	0.032	0.027	0.20	0.39	0.11

[1] Ocean water (Rankama and Sahama, 1950, p. 287, 290). Some components range greatly in concentration; upper limits shown here.

[2] Well 6/11-11A2, The Texas Co. (Piper *et al.*, 1953, p. 207, 210). NH_4 not determined—average of two other analyses from Huntington Beach (p. 210). Jenson's (1934) average of 7 from Huntington Beach is nearly 200 ppm.

[3] Amerada Petroleum Corp. well Drouin No. 4, sec. 25, T. 4 N., R. 2 E., producing gas and brine from 4400 to 4420 ft. Collected by C. R. McClure, Calif. Division of Water Resources, May 13, 1955. Analyst, R. O. Hansen, U. S. Geological Survey.

[4] Seaboard well No. S. T. U. 305–13, sec. 13, T. 15 S., R. 17 E., from 4700-foot depth. Collected by Calif. Division of Water Resources, April 20, 1954.

[5] Kentucky and Ohio Gas Co. No. 1 Hutchenson well producing from Corniferous Formation, 1506 feet (McGrain, 1953, p. 12, 14).

[6] Old oil-test well on Bear Creek, 1 mi. SE of Wilbur Springs, sec. 27, T. 14 N., R. 5 W.; seeping overflow. From Knoxville Formation (W. B. Myers, personal communication). Analysts, H. Almond and S. Berman, U. S. Geological Survey.

TABLE 2.—ANALYSES OF VOLCANIC HOT SPRINGS OF THE SODIUM-CHLORIDE TYPE, COMPARED WITH AVERAGE IGNEOUS ROCKS

(In parts per million)

	Steamboat Springs, Washoe Co., Nevada[1]	Morgan, Tehama Co., California[2]	Norris Basin, Yellowstone Park, Wyoming[3]	Upper Basin, Yellowstone Park, Wyoming[4]	Wairakei, New Zealand[5]	Average igneous rocks[6]
Temp. °C.	89.2	95.4	84	94.5	>100	
pH	7.9	7.83	7.45	8.69	8.6	
SiO_2	293	233	529	321	386	593,000
Fe				Tr.		50,000
Al				0		81,300
Ca	5.0	79	5.8	4	26	36,300
Mg	0.8	0.8	0.2	Tr.	<0.1	20,900
Sr	1	10[7]				220
Na	653	1400	439	453	1130	28,300
K	71	196	74	17	146	25,900
Li	7.6	9.2	8.4		12.2	22
NH_4	<1	<1	0.1	0	0.9	
As	2.7	2.2	3.1			5
Sb	0.4	0.0	0.1			1(?)
CO_3	0	0	0	66		
HCO_3	305	52	27	466	35	1620
SO_4	100	79	38	15	35	1560
Cl	865	2430	744	307	1930	314
F	1.8	1.5	4.9	21.5	6.2	700
Br	0.2	0.8	0.1			1.6
I	0.1	<0.1	<0.1			0.3
B	49	88	11.5	3.7	26.2	3
S_2O_3				2		
H_2S	4.7	0.7	0	0	1.1	
CO_2					11	
Sum	2360	4580	1890	1680	3740	841,000
Ratio by wt.						
HCO_3[8]/Cl	0.35	0.021	0.036	1.9	0.018	5.2
SO_4/Cl	0.12	0.033	0.051	0.049	0.018	5.0
F/Cl	0.0021	0.0006	0.0066	0.070	0.0032	2.2
Br/Cl	0.0002	0.0003	0.0001			0.005
I/Cl	0.0001	<0.00004	<0.0001			0.001
B/Cl	0.057	0.036	0.015	0.012	0.013	0.01
K/Na	0.11	0.14	0.17	0.038	0.13	0.91
Li/Na	0.012	0.0066	0.019		0.011	0.00078
Ca + Mg/Na + K	0.0080	0.050	0.012	0.008	0.020	1.1

[1] Spring 8, Main Terrace, collected by White, August 9, 1949, analyzed by W. W. Brannock, U. S. Geological Survey.

[2] Growler spring. The group is located just south of Lassen Volcanic National Park, sec. 11, T. 29 N., R. 4 E. Collected by White, July 29, 1949, analyzed by W. W. Brannock, U. S. Geological Survey.

[3] Unnamed spring with periodic discharge and precipitating abundant silica, 200 feet southwest of Pearl geyser. (Allen and Day, 1935, p. 482.) Collected by White, August 3, 1951, analyzed by P. W. Scott and W. W. Brannock, U. S. Geological Survey.

[4] Sapphire Pool (Allen and Day, 1935, p. 103, 249).

[5] Water erupted from drill hole 4, eastern part of thermal area (Wilson, 1955, p. 37). Carbonic acid recalculated as CO_2, HBO_2 as B, H_2SiO_3 as SiO_2; 0.15 ppm HS included in H_2S.

[6] Rankama, 1954, p. 135. All C and S assumed to be oxidizable to carbonate and sulfate so that ratios of all analyses may be compared.

[7] Spectrographic determination.

[8] All carbonate and bicarbonate calculated as HCO_3.

TABLE 3.—TENTATIVE CRITERIA FOR RECOGNITION OF MAJOR TYPES OF GROUND WATER OF DIFFERENT ORIGINS

	Chemical composition	Isotopic composition	Heat relations
Meteoric water	Controlled by surface waters, bedrocks	Same as or close to surface waters	Near "normal"
Sea water (direct from ocean)	Same as or very similar to ocean (very low in I and and other nutrients)	Same as or close to ocean	Near "normal" or sub-subnormal
Connate water (chloride types)	Enriched in I, B, SiO_2, combined N, Ca, soluble organic components and low in SO_4 and Mg relative to ocean	D/H $\gtrless$ ocean, O^{18}/O^{16} > ocean	"Normal" to moderately thermal
Metamorphic water	Little known. High in combined CO_2 and B, low in Cl relative to ocean?	Little known. D/H $\gtrless$ ocean? O^{18}/O^{16} > ocean?	"Normal" to moderately thermal
Magmatic water (volcanic sodium-chloride type)	Relatively high in Li, F, SiO_2, B, S, CO_2, low in Ca, Mg, combined N(?)	Little known. D/H < ocean? O^{18}/O^{16} > ocean	Strongly thermal in active systems

TABLE 4.—APPROXIMATE RANGES IN CHEMICAL COMPONENTS OF OCEAN WATER, OIL-FIELD BRINES DOMINATED BY CHLORIDE, AND VOLCANIC SODIUM-CHLORIDE SPRINGS

Ratios, by weight	Ocean*	Oil-field brines†	Volcanic hot springs**
HCO_3/Cl††	0.0074	0.0001–1	0.01–3
SO_4/Cl	0.14	0.00000–1	0.01–0.5
F/Cl	0.00007	0.00001–0.001	0.0005–0.1
Br/Cl	0.0034	0.0001–0.01	0.0001–0.001
I/Cl	0.000003	0.00003–0.02	0.00001–0.0005
B/Cl	0.00024	0.00001–0.02	0.01–0.1
K/Na	0.036	0.001–0.03	0.03–0.3
Li/Na	0.00001	0.0001–0.003	0.003–0.03
Ca + Mg/Na + K	0.153	0.01–5	0.001–0.2
Concentrations, ppm			
SiO_2	0.04–8	10–100	100–700
Ca	400	10–20,000	1–100
Mg	1272	1–10,000	0.1–10
Sr	13	1–3000	0.1–10
Ba	0.05	nil–5000	0–1
NH_4	<0.005–0.05	0–500	nil?
NO_3	0.001–0.7	nil–100	nil?
As	0.002–0.017	?	0.1–10
Sb	Trace	?	0.0–1
H_2S	0–60	0–3000	0–10
CH_4	?	large	nil
Water-soluble organic compounds	slight	large?	nil

* Rankama and Sahama, 1950, p. 290.

† From Table 1 and other data (*see* text).

** From Table 2 and other data (*see* text).

†† All combined carbonate and bicarbonate calculated as HCO_3.

Harmon Craig, G. Boato, and the present writer (*see* initial paper, Craig, Boato and White, 1956), and will therefore be mentioned only briefly here.

The isotopic analyses of only a few connate waters have been published (Rankama, 1954. p. 159, 252). These few indicate lower deuterium and higher O^{18} contents than for ocean water. Deuterium content of the Wilbur oil test well (Table 1) is also a little lower (2 per cent) relative to the standard than ocean water, and the O^{18} is higher (0.3 per cent). According to Harmon Craig (personal communication), Texas brines are isotopically very similar to water from the oil test well.

The isotopes of the volcanic sodium-chloride waters are very similar to those of the surface waters of each specific area in which a spring emerges (Craig *et al.*, 1956). The hydrogen of the hot springs is almost identical to that of the surface waters, but the oxygen is commonly several tenths of a per cent heavier. If the differences were caused by volcanic water mixing with meteoric water, the hydrogen of each volcanic water must be nearly the same as that of the particular meteoric water with which it mixes. This demand on coincidence is highly improbable; a much more reasonable explanation, supported by some evidence, is that part of the oxygen of meteoric water has exchanged with the heavier oxygen of silicates. This "oxygen shift" may well conceal a small difference in oxygen and hydrogen that is actually caused by a contribution of volcanic water. The upper limit of the volcanic contribution appears to be in the order of a few per cent for the analyzed spirngs. There is no compelling isotopic evidence for the presence of any magmatic water in these springs. On the other hand, the discharge of heat and mineral matter are of such magnitude and nature that a volcanic source seems essential (White, 1957). Except for the unlikely possibility that the mineral matter is evolved anhydrously, water is also an essential volcanic component. It is believed to be present in small amount in the near-surface mixtures (probably 5 per cent or less), but is diluted with meteoric water almost beyond recognition by isotopic methods.

Tritium, the radioactive isotope of hydrogen, with a half life of about 12.5 years, is produced in the atmosphere by cosmic-ray bombardment of nitrogen (Libby, 1954). Tritium is a minor component of relatively young meteoric water but is not detectable in waters out of contact with the atmosphere for 50 years or more.

Tritium has been found in volcanic hot springs in quantities that are similar to those of associated meteoric waters (Von Buttlar and Libby, 1955). The tritium data not only confirm the conclusion that the water of the hot springs is dominantly of surface origin but also prove that subsurface travel times of a least part of the meteoric water are slight, probably not exceeding a few years.

No tritium analyses of oil-field brines are known to the writer. The T content of Wilbur Springs, which is shown below to have the characteristics of connate water, is very low (Fred Begemann, personal communication). The small amount of tritium in the water is believed to result from slight dilution with meteoric water near the surface.

Total Dissolved Solids

Oil-field waters contain from a little more than 1 per cent of the dissolved matter of sea water to about 10 times as much. Table 1 contains a range in salinity that includes nearly all oil-field brines that are dominated by chlorides. Crawford (1942) and others believe the dilute waters result from the flushing action of circulating meteoric waters. Apparently few oil-field brines in Tertiary rocks contain more than 15,000 ppm of chloride (*see* for example, Jenson, 1934), as compared to about 19,000 for average sea water. The lower salinity of the connate waters is commonly believed to result from some dilution by meteoric water. De Sitter, however (1947, p. 2039), has suggested that the brines with more dissolved matter than sea water have been concentrated by "sieve" action of fine-grained sediments, which behave as semipermeable membranes allowing water molecules to pass but retarding salt ions. If this or some other mechanism involving separation of water from ions has formed the high-concentration brines, the connate water that had escaped should contain less dissolved matter than the original brine. This could explain, at least in part, the scarcity of California brines of Tertiary age with chlorinities above that of sea water (Jensen, 1934). Timm and Maricelli (1953), on the other hand, believe that high-concentration brines escape first and leave dilute connate water behind. In spite of the fact that the mechanism is not clear, it appears that connate waters evolve into types that are somewhat more dilute, and other types that are more concentrated than sea water, without involving dilution with meteoric water or contact with salt beds. Many connate waters,

however, are clearly mixed with meteoric water.

Volcanic hot spring waters generally range from about 1000 to 5000 ppm of dissolved matter. They are therefore more dilute than most oil-field brines. High-density volcanic waters before mixture with meteoric water (White, 1957) probably contain at least as much dissolved matter as ocean water and perhaps much more.

Halogen Elements

Fluorine is relatively low in ocean water and seems to be slightly higher in most oil-field waters in spite of the fact that calcium is also generally enriched (Schoeller, 1956, p. 94). F is relatively high in volcanic hot springs of the sodium-chloride type and attains concentrations as high as 20 ppm (Table 2) in alkaline waters with little calcium. Even though the volcanic sodium-chloride waters are high in F some volcanic gases have far higher F/Cl ratios (Zies, 1929, p. 4); this suggests that much has been fixed at depth as fluorite or in silicates such as the micas.

The Br/Cl ratio of ocean water is 0.003 (Table 1), which is very similar to that of average igneous rocks, 0.005. (The reliability of the bromine content of igneous rocks, as for many trace elements, is uncertain; *see* Correns, 1956, p. 184–187). Oil-field brines commonly have about the same ratio (Schoeller, 1956, p. 97). No major difference is to be expected, in view of the scarcity of bromine-concentrating organisms (Vinogradov, 1953, p. 106). This contrasts strongly with differences in iodine ratios as will be seen.

The apparent Br/Cl ratio of the volcanic hot springs (about 0.0002) may be an order of magnitude lower than that of average connate water. More study is necessary to determine whether the difference is real or is a result of lack of precise analyses of dilute volcanic waters.

Differences in the iodine-chlorine ratios are marked. The ratio for ocean water is 0.000003 (Table 1); the mean for all oil-field brines is about 0.001 (Schoeller, 1956, p. 101, 106). Iodine is apparently essential in the growth processes of all plants and animals, and is particularly enriched in marine algae (Vinogradov, 1953, p. 69–73, 91–93, 153–154; Goldschmidt, 1954, p. 602–612). According to Vinogradov (1953, p. 70–72), and Dzens-Litovsky, (1944), the fine-grained carbonaceous ocean sediments are very rich in iodine, with a concentration in the order of 0.01 per cent or more than a thousand times that of sea water. Iodine is apparently deposited with the remains of marine organisms; when the organic compounds decompose a considerable part of the iodine dissolves in the interstitial water. Much iodine remains in the sediments, however, and the I/Cl ratio is more than a thousand times higher than in ocean water (from calculations based on Correns, 1956, p. 226).

The average I/Cl ratio of the calcium-chloride brines of high salinity (Cl > 100,000 ppm) is about 0.0001, or in the order of 30 times that of sea water (Schoeller, 1956, p. 101, 109–111; Chajec, 1949; Lamborn, 1952; McGrain, 1953; Schoewe, 1943). The sodium-chloride brines, for the most part Tertiary in age, tend to have much higher I/Cl ratios, in the order of 0.003 (Schoeller, 1956, p. 101; Bemmelen, 1949, p. 185–190; Piper *et al.*, 1953, p. 207–216; and Sawyer, Ohman, and Lusk, 1949).

The iodine-chlorine ratios of the volcanic sodium-chloride springs (Table 1) are in the order of 0.0001 and are lower than in all connate brines, except for some of the highly saline calcium-chloride waters. As might be expected, the I/Cl ratios of igneous rocks and volcanic hot springs tend to be intermediate between sea water and most connate brines.

Alkali Elements

The K/Na ratio is relatively high in rivers and in dilute ground waters (Schoeller, 1956, p. 136) and commonly ranges from 0.3 to 0.6. Waters from granitic and rhyolitic rocks tend to be particularly high in potassium. The only surface waters that are consistently higher are acid-sulfate hot springs in rhyolitic rocks, where alkalies have been derived directly from chemical attack on the adjacent rocks (White, 1957). Schoeller has shown that, on the average, the ratio decreases with increasing salinity. The K/Na ratio of ocean water is only 0.036 and that of most oil-field brines is still lower; the mean is 0.02 for the waters studied by Schoeller (p. 137). These also indicate decreasing ratios with increasing salinity. These changes reflect progressive base exchange of potassium in the waters for sodium from silicate minerals, and the conversion of low-potassium to high-potassium clays.

The K/Na ratio of volcanic sodium-chloride springs is commonly about 0.1 (Table 2). It seems to be highest (up to about 0.25) in nearly neutral springs high in free CO_2, but is as low

as about 0.03 in some of the most alkaline dilute waters with pH's of 9 or more. The limited data also suggest, in contrast to other waters, that the ratio tends to increase with increasing salinity. These relationships are interpreted to mean that volcanic waters near their source are relatively high in potassium; perhaps the K/Na ratio is as high as 0.5 in waters from silicic volcanic rocks. As the waters react with adjacent rocks to form sericite, potassium clays, and in some places adularia, they are enriched in sodium and combined CO_2 and are impoverished in potassium. The K/Na ratios of the most impoverished volcanic hot springs waters are about equal to the average of oil-field brines.

Lithium has seldom been determined in oil-field waters. The lithium content of the Rio Vista analysis (Table 1) is typical of a dozen analyses of central California gas fields and is also very similar to that of the Wilbur oil-test well, and oil-field waters analyzed by Vinogradov (1948, p. 26), and Howard (1906, p. 284). One Hungarian oil-field water, according to an old analysis quoted by Telegdi-Roth (1950, p. 81), is reported to be high in Li, but others (p. 83, 84) contain little. Many more reliable analyses are needed, but the meager data suggest that the very low Li/Na ratio of sea water (0.00001) is increased an order of magnitude or more in many oil-field waters (0.0001–0.003). The geochemistry of lithium is not sufficiently well known to explain the suggested enrichment. Lithium is concentrated somewhat in plants relative to soils, but it has no known physiological function (Goldschmidt, 1954, p. 134–135). It is concentrated in marine shales (p. 135), and some may be released when clay minerals are reconstituted. More data are clearly needed.

In contrast to connate brines, the waters of volcanic hot springs have commonly been analyzed for lithium. Of all natural waters that occur at the surface, those of the volcanic sodium-chloride type are the most enriched in lithium. The Li/Na ratios of the analyses of Table 2 range from 0.006 to about 0.02, and the average of all analyses of this type of water that are known to the writer is about 0.01. Many volcanic hot springs of the sodium-chloride type have approximate ratios of alkalies, by weight, of 100 Na:10 K:1 Li. The corresponding atomic ratios are 100 Na:6 K:3.3 Li. The atoms of lithium, a relatively rare atomic species, are nearly as abundant as those of potassium. Stated in another way, lithium constitutes about 0.3 per cent or 3000 ppm of the dissolved solids of Steamboat Springs water but only about 22 ppm of average igneous rock (Rankama, 1954, p. 135) and 46 ppm of the average glassy rhyolites and dacites of western United States (Coats, 1956, p. 76).

Lithium in the waters has been enriched about 100 times over its content in igneous rocks, but sodium has been enriched only 10 times in spite of similar solubilities and base-exchange properties. The high content of lithium in volcanic waters, with Li/Na ratios that are generally one or two orders of magnitude higher than probably connate waters, may prove to be a very significant criterion in distinguishing these waters.

The high lithium content of the volcanic sodium chloride springs is a weighty argument favoring a volcanic origin for the alkalies, which were probably transported as soluble alkali chlorides in water or very dense vapor (White, 1957). Allen and Day (1935, p. 114–118) reached no certain conclusion but favored the transport of halogens as volatile alkali halides rather than as halogen acids in spite of the known low volatilities of the halides. The possibilities for transport of nonvolatile matter in solution in dense vapors were indicated by Schröer (1927) and Ingerson (1934). The evidence, considering all the halogens and alkalies, favors a dominantly volcanic source for both groups of elements. The original ratios of the alkali metals, however, have clearly been modified by later exchange of cations with wall rocks. Sodium is generally enriched in the waters by exchange, potassium is lost, and lithium may decrease slightly, judging from relations at Steamboat Springs, where the lithium content of hydrothermally altered granodiorite appears to be somewhat greater than that of fresh rocks.

Very little is known of the rubidium and cesium contents of various waters. These elements should be given more attention (Borovik-Rommanova, 1946, p. 145–180).

Sulfur

Nearly all sulfur of sea water is present as sulfate; the average concentration is about 2600 ppm and the SO_4/Cl ratio is 0.14 (Table 1), but in basins of restricted circulation some of the sulfur is present as H_2S in quantities as high as 60 ppm (Goldschmidt, 1954, p. 529). Most oil-field brines, on the other hand, are relatively low in sulfate as compared to sea water (De Sitter, 1947; Schoeller, 1956, p. 115; Chebotarev, 1955, p. 159). Rogers (1917, p.

93–94) believed that low sulfate was the most characteristic feature of all oil-field waters. The sulfate-chloride ratios of the oil-field brines of Table 1 range from essentially zero to about 0.001.

Other oil-field waters are considerably higher in sulfate. Of the 667 analyses considered by Chebotarev (1955, p. 153), anions of 28 are dominated by sulfate. The mean depth of the sulfate waters was 1800 feet, of bicarbonate waters, 2300, and of chloride waters, 3500 feet. The relative shallowness and low chloride content of the sulfate waters is an indication that they are related to oxidation and flushing action of meteoric water and that, of all types of oil-field waters, they probably contain the lowest proportion of connate water. The sulfate of sea water buried with sediments has generally been reduced entirely or in large part to sulfide by the action of sulfur-reducing bacteria (Bastin and Greer, 1930; Ginter 1934; Emery and Rittenberg, 1952, p. 789–791; Beerstecher, 1954, p. 58–60). The bacteria reduce sulfate, utilizing energy available from oxidation of organic material to CO_2 and other substances (Schoeller, 1956, p. 115–119). Emery and Rittenberg have shown that most of the sulfate in basin sediments off the coast of Southern California has been reduced to H_2S and precipitated as sulfide when the sediments have been buried to depths of only a few feet. Much of the sulfide that is formed reacts with ferric oxides to form iron sulfides (Emery and Rittenberg, 1952, p. 791–793), but some may remain in solution as H_2S or as the HS^- ion. H_2S has not commonly been determined in oil-field brines; the available data are summarized by Schoeller (1956, p. 115). According to Rogers (1917, p. 100–101) H_2S does not exceed 350 ppm in the waters of the East Coalinga field, and is generally less than 50 ppm. H_2S is generally absent in Texas brines, but a content as high as 1000 ppm was noted by Berger and Fash (1934) and 2400 ppm by Ginter (1934, p. 922); 12 per cent of the accompanying gas was H_2S.

The sulfur of volcanic hot springs occurs dominantly as sulfate, but the waters commonly contain a few ppm of H_2S, and a few per cent is in the accompanying gases. Some but perhaps not all volcanic waters at depth contain considerable sulfide, some of which is apparently oxidized by mixing meteoric waters containing dissolved oxygen.

The sulfate of volcanic sodium-chloride springs (Tables 2, 4) commonly ranges from 50 to more than 100 ppm, and the sulfate-chloride ratio from about 0.01 to 0.3 or more; it is believed to be much higher in volcanic waters found at the surface than in most connate waters.

Carbon Dioxide

Ocean water contains an average of 140 ppm of combined CO_2, calculated as HCO_3. The HCO_3/Cl ratio is about 0.007. The corresponding ratios and CO_2 concentrations of most oil-field brines of low to moderate salinity are higher than ocean water (Table 1). Of the 667 oil-field waters considered by Chebotarev (1955, p. 153, 159), the anions of only 34 were dominated by bicarbonate. As mentioned above, the mean depth of these samples was 2300 feet, intermediate between the mean depth of sulfate waters (1800 feet) and chloride waters (3500 feet). The bicarbonate waters are less likely, because of their greater depth, to be as strongly influenced as the sulfate type by flushing action of meteoric water, but they are also not likely to contain as high a proportion of connate water as the chloride type.

Schoeller (1956, p. 116–120) has summarized evidence for a general decrease in sulfate with depth, accompanied by an increase in combined CO_2. The latter in turn is usually associated with a decrease in calcium because of mass-action effect and the low solubility of calcium carbonate.

Bicarbonate and free CO_2 are products of the decomposition of organic matter and the activity of sulfate-reducing bacteria. The energy is supplied by oxidation of organic matter, with the oxygen derived from sulfate. CO_2 is then available for chemical reaction. This may explain the relatively high bicarbonate of many oil-field brines of moderate salinity.

Oil-field gases nearly always contain some CO_2 and a few consist largely of this gas (Anderson and Hinson, 1951; Miller, 1936, 1937; Dobbin, 1935; Schoeller, 1956, p. 87). This CO_2 was probably derived largely from organic carbon.

The highly saline calcium-chloride brines generally contain little combined CO_2 in spite of pH's that are generally in the range of 5–7. These brines seem to be enriched in Ca relative to Na to such an extent that, because of mass action, the solubilities of carbonate and bicarbonate are very low. There is no evidence, however, for a corresponding increase of CO_2 in the associated gases. The scarcity of CO_2 in

or near the high-density calcium-chloride brines is a puzzling fact.

Volcanic hot springs of the sodium-chloride type commonly contain much combined CO_2; HCO_3/Cl ratios range from less than 0.1 to at least 2 (Table 2). All these waters also contain free CO_2 not reported in ordinary water analyses. The free CO_2 content was not determined in the Steamboat analysis shown in Table 2, but a somewhat similar spring with a pH of 6.5 contained about 470 ppm of free CO_2 (computed from analysis of total CO_2 by Harmon Craig).

Near their source, the dense volcanic emanations probably contain much free CO_2 but little combined CO_2 (White, 1957); after condensation of steam, the waters react with wall rocks and dissolve alkali and alkaline-earth elements as soluble bicarbonates. The quantity of bicarbonates and carbonates in solution is a rough measure of the rock alteration produced by the waters, with the exception of any alteration by free halogen acids. The pH gives a rough indication of the quantity of free CO_2 available for further alteration. High pH's indicate that most of the original CO_2 has already reacted, or that the water was so hot upon arrival at the surface that most of the free CO_2 was boiled off before collection of the sample (White, Sandberg, and Brannock, 1953, p. 119–120).

Many volcanic hot springs have higher ratios of combined CO_2 to chloride than most oil-field brines but there is much overlap. A high content of CO_2 is probably less diagnostic of volcanic waters than many geologists have believed.

Boron

The average boron content of sea water is about 4.6 ppm (Table 1), and the boron-chloride ratio is roughly 0.0002. The data for oil-field brines are summarized by Schoeller (1956, p. 156). Few brines in the United States have been analyzed for boron until very recently but California brines apparently contain from 10 to 100 times as much, relative to chloride, as sea water (Scofield, 1933, p. 127–128; Table 1).

A relatively high content of boron characterizes most Russian oil-field brines (Tzeitlin, 1936). The boron-chloride ratios show a considerable scatter, but Kazmina's graph (1951, p. 302) indicates a strong tendency for inverse relationships, and boron is relatively low where chloride is high and vice versa. The sodium-chloride brines, with salinities near or below sea water, have an average boron content of 106 ppm, or 0.68 per cent of the mineral content according to Tageeva (1942), but brines of very high salinity, also high in calcium, may have little more boron than normal sea water. The relatively low solubility of the calcium borates may explain the low boron content of brines that are high in calcium (Schoeller 1956, p. 157).

Boron is greatly enriched in some marine sediments (Landergren, 1945; Gulyaeva, 1948, p. 833–835; Goldschmidt, 1954, p. 280–288), but little is known of its chemical association. The boron content of argillaceous marine sediments generally ranges from 30 to 1000 ppm, in contrast to 4.6 ppm in average ocean water and 3 ppm in average igneous rock. It is clear that some of the boron of sediments goes back into solution in connate brines.

The boron content of volcanic sodium-chloride springs is usually in the order of 10 to 100 ppm; the boron-chloride ratios are generally from about 0.01 to 0.1, as compared to 0.00001 to 0.02 for most oil-field brines. A high boron-chloride ratio is usually an indicator of volcanic water, as compared to ordinary oil-field brine. Waters of possible metamorphic origin with very high B/Cl ratios are considered below.

Combined Nitrogen

Combined nitrogen is one of the chief nutrients for organisms in sea water, thereby explaining the low concentration of ammonium and nitrate in the sea. Emery, Rittenberg, and Orr (Emery and Rittenberg, 1952, p. 776–780; Emery, Orr, and Rittenberg, 1955, p. 300–303; Rittenberg, Emery, and Orr, 1955, p. 29–38) have shown that much nitrogen-bearing organic matter in the ocean and in bottom sediments is decomposed soon after burial, presumably by bacteria. Some amino acids are more stable and decompose only after long intervals of time or at rather high temperatures (Abelson, 1954). Nitrate is produced in oxidizing environments, but ammonia forms in the reducing environment provided by sediments with appreciable organic content.

Ammonium ion, although generally not determined, seems to be one of the characteristic components of oil-field brines. Jensen's (1934) analyses of California oil-field brines indicate that nearly all contain ammonium with a mean of about 90 ppm. For California waters with salinities close to sea water, the NH_4 con-

tent is in the order of 150 ppm. It is present in nearly all Illinois oil-field brines (Meents *et al*, 1952) and ranges up to 309 ppm and averages about 40 ppm. The data for several other areas are summarized by Schoeller (1956, p. 145). The mean concentrations, in mg/l are: Roumania, 155; Polasna-Krasnokamsk, Russia, 122; Hungary, 10.6.

Nitrate has been searched for in only a few brines and seems to be enriched in some, relative to ocean and surface waters. Nitrate is formed in preference to, or from, ammonia where the oxidation potential is sufficiently high (Rittenberg *et al.*, 1955, p. 29–38).

Ammonia has commonly been considered a volcanic component because it occurs in many volcanic and hot-spring gases and in fumarole deposits. If it is volcanic, however, its very erratic distribution has never been explained satisfactorily. It is absent in most Yellowstone hot springs (Allen and Day, 1935, p. 249, 373, 469), and it shows no systematic relation to hydrogen or other components (p. 86) that are likely to be volcanic in origin. Shepherd (1938, p. 322) suspected that ammonia is nonvolcanic and did not find it in any of his volcanic gases, even though elemental hydrogen and nitrogen are abundant in some of the samples. Rubey (1955, p. 642–645) concluded that there is no strong evidence for a magmatic source of ammonia. Rayleigh (1939) on the other hand, believed that combined nitrogen, presumably as ammonia, occurs in granite. Urey (1952, 1956) maintains that ammonia and methane were both important components of an early reducing atmosphere; presumably he also believes they should be present in magmatic gases.

Both ammonium and nitrate have been searched for but not found at Steamboat Springs, whose waters emerge from granitic rocks. It is possible that ammonia is not volcanic and that the ammonia of volcanic fumaroles and hot springs is derived entirely from sediments. A systematic search should be made for combined nitrogen in volcanic gases and waters that emanate from granitic and high-grade metamorphic rocks. If none is found, an organic origin is indicated for all combined nitrogen.

Combined nitrogen is characteristic of connate brines but may be lacking in waters of direct volcanic origin.

Hydrocarbons and other Organic Compounds

Hydrocarbons are, of course, abundant in gases and oils associated with oil-field brines. The lower hydrocarbons of the methane group are generally the most abundant. Little is known about the water-soluble organic acids and phenols that occur in many, if not most, connate brines (Shapiro, 1951; Sukharev, 1951). Smith (1931, p. 899) and Sukharev (1951) have been particularly interested in the napthenic acids in waters and their possible relation to petroleum deposits.

Methane and occasionally ethane have been found in the gases of some volcanic hot springs, but their distribution is highly erratic. Methane is absent, for example, in 5 of the 40 analyses of Yellowstone spring gases reported by Allen and Day (1935, p. 86) but is as much as 13 per cent of the total in one of the analyses. The proportion of methane seems unrelated to other components, including free hydrogen. It was searched for but not found in the gases emerging from granitic rocks at Steamboat Springs. Shepherd (1931, p. 81–82; 1938, p. 321, 326) was unable to find methane in Kilauea gases or in any of the gases he obtained by heating volcanic rocks, in spite of rather abundant hydrogen in some of the samples. He concluded that methane indicates contamination from sedimentary rocks or, presumably, from organic matter covered by lava flows, and the writer concurs. Water-soluble organic acids, phenols, and hydrocarbons, when present in a water, are indicative of a connate contribution from sedimentary rocks.

Silica

The silica of ocean water ordinarily ranges from less than 0.1 to about 8 ppm in spite of the fact that it is being contributed continuously in higher concentration by rivers. Its solubility with respect to amorphous silica in cold sea water is about 75 ppm according to Krauskopf (1956). The activity of silica-secreting organisms, the very slow rates of dissolution at low temperature, and perhaps differences in solubility of opaline and amorphous silica account for the low silica content of the ocean. The silica of oil-field brines is somewhat higher; it commonly ranges from about 10 to 50 ppm but rarely reaches as much as 90 ppm (Table 1). In view of the fact that the solubility with respect to amorphous silica at temperatures found in oil fields is from about 150 to more than 400 ppm, White, Brannock, and Murata (1956) suggest that diatoms are slowly dissolved, but seldom at a rate that attains saturation. As the diatoms dissolve, quartz and

chalcedony, which are low-solubility forms of silica, are presumably deposited.

The solubility of amorphous silica in hot-spring waters (White, Brannock, and Murata 1956) ranges from about 110 ppm at 25°C. to about 315 ppm at 90°C. "Soluble" silica seems to be nonionized monomeric silicic acid (probably H_4SiO_4). It may polymerize very slowly from superstaturated waters to form colloidal molecules. Because of the sluggishness of the reactions, supersaturated hot spring waters are not uncommon, and many volcanic sodium-chloride waters are saturated at vent temperatures. The silica content of the volcanic springs of Table 2 ranges from 150 to more than 500 ppm.

The silica content of volcanic hot springs is nearly always significantly higher than that of oil-field brines. Volcanic springs of the calcium-bicarbonate type (White, 1957; White, Brannock, and Murata, 1956, p. 51), however, are commonly as low as 50 or 60 ppm, and heated connate brines that are rapidly altering or dissolving silicate rocks such as serpentinite may contain amounts within the normal range for volcanic hot springs.

Alkaline-Earth Elements

Concentrations of the alkaline-earth elements are strongly dependent on pH, temperature, and other substances in the waters.

Magnesium is strongly dominant over calcium in sea water; the ratio is about 3 to 1 (Table 1). Nearly all oil-field brines, however, show a reversal of relationships with the Mg/Ca ratio as low as 0.03. The change probably has some bearing on the origin of diagenetic dolomite.

Probably because carbonate and bicarbonate are relatively high, the more dilute brines commonly have a lower ratio of $\frac{Ca + Mg}{Na + K}$ than ocean water. Calcium is greatly enriched however, in most, if not all, of the highly saline oil-field brines and in a few waters with salinities similar to sea water (Hudson and Taliaferro, 1925). Many of the very saline brines are relatively low in pH (Meents *et al.*, 1952) and range from 5 to 7 in spite of the fact that combined CO_2 is very low. The low content of combined CO_2 seems to be related to the very high calcium content and to calcium-carbonate equilibria.

The calcium content of most volcanic hot springs in igneous rocks is very low relative to the alkalies because of the low solubility of calcium and magnesium carbonates at high temperature (Garrels and Dreyer, 1952, p. 339, 340; Miller, 1952; and White, 1957). In the waters, calcium is generally greatly dominant over magnesium, probably because the latter is selectively fixed in argillic minerals during rock alteration. Ca and Mg are commonly very low even in neutral and slightly acid waters with abundant free CO_2, probably because these waters have been at much higher temperatures at depth. Volcanic spring waters of the calcium-bicarbonate type (White, 1957) are believed to attain their character at relatively low temperature through the mixing in limestone beds of a little volcanic water with very abundant meteoric water. This is consistent with the fact that springs of this type seldom if ever have boiling temperatures at the surface.

The ratios of calcium and magnesium are likely to be similar in oil-field brines and volcanic sodium-chloride springs, but in the latter the concentrations relative to the alkalies are generally low.

Strontium is probably present in all connate and volcanic waters but has seldom been determined. It seems to be most abundant in oil-field brines that are low in combined CO_2 and attains concentrations as high as 2600 ppm in West Virginia brines (Price *et al.*, 1937, p. 67, 98), and 3550 ppm in Pennsylvania brines (Mills and Wells, 1919, p. 39). The solubilities of strontium carbonate and sulfate are high enough to permit detectable concentrations in most natural waters.

Barium is relatively abundant in oil-field brines that have little or no sulfate (Heck, 1940). Some West Virginia brines, for example, contain little sulfate but as much as 5500 ppm of barium (Price *et al.*, 1937, p. 50–51, 91). The high barium content is clearly related to bacterial reduction of sulfate in the water and in sediments (Heck, 1940). Barium goes into solution when all or nearly all sulfate in the water has been reduced. Barite is readily precipitated if these waters are later oxidized or if they mix with normal meteoric water.

The barium content of volcanic hot springs is seldom appreciable, perhaps because of the relatively high sulfate content that characterizes these waters. If volcanic water at depth is low in sulfate, it may, of course, contain barium.

Other Elements

More than 1,000 ppm of iron has been reported in a few oil-field brines (Schoeller, 1956

p. 151–153) but most contain about 10 ppm or less. The content differs greatly in waters that are otherwise very similar (Meents *et al.*, 1952). Only traces of iron are found in volcanic hot springs of the sodium-chloride type.

As much as 330 ppm of AL_2O_3 has been found by Meents *et al.* (1952, p. 36) in Illinois brines, most of which are very high in salinity. The average alumina content is 20–30 ppm. Alumina, generally in smaller quantities, has been reported in many other oil-field brines. Volcanic hot springs of the sodium-chloride type are notably low in alumina; they seldom if ever contain more than 1 ppm.

Manganese is a minor component of many oil-field brines and is rather commonly in quantities as much as 1 ppm and exceptionally more than 10 ppm (Meents *et al.*, 1952, p. 37; Schoeller, 1956, p. 151). The quantity in volcanic sodium-chloride springs has seldom been determined but appears generally to be less than in oil-field brines.

A trace of arsenic was found by Howard (1906, p. 284) in a West Virginia brine and the surprising amount of 5.8 ppm was reported by Telegdi-Roth (1950, p. 81) from the same Hungarian brine that purportedly contains 84 ppm of Li. Mercury has been reported from wells in the Cymric field of California (Stockman, 1947). Oil-field brines should be searched systematically for arsenic, antimony, and mercury to determine whether appreciable quantities are present. Volcanic hot springs of the sodium-chlorice type commonly contain at least 1 ppm of arsenic and detectable amounts of antimony. Their mercury content is not yet well known because of analytical problems.

Nonvolcanic Hot Springs

Discussion

Many springs of low to moderate temperature have compositions differing markedly from springs that most clearly have volcanic contributions. The dilute waters are best explained as deeply circulating meteoric waters that are heated by rock conduction and have picked up some additional mineral matter. Some moderately to highly mineralized meteoric waters have no doubt come in contact with salt beds. The possibility must now be recognized, however, that some springs may be fed by connate water from sediments that are being compacted, or by water from rocks that are being progressively metamorphosed. According to Clarke (1924, p. 631), as mentioned previously, average shale has 5.0 per cent water, slate has 3.8 per cent, and schist 2.0 per cent. No averages are given for gneiss, but individual analyses range from 0.4 to 1.8 per cent (p. 630) and have a probable average t is not much greater than the 0.65 per cent reported for average granodiorite (Nockolds, 1954, p. 1014). It is evident that very large quantities of water, not represented by normal oil-field brines or by volcanic hot springs, are driven off from sediments during their progressive compaction and metamorphism. Water-saturated shale that decreases in porosity from 20 to 10 per cent during compaction must lose 10^{11} liters of water per km^3 of sediments. Shale with a water content of 5 per cent also must lose approximately 10^{11} liters of water per km^3 if metamorphosed to gneiss with a water content of 1 per cent. In both situations the quantity of water driven off from a cubic kilometer of rock happens to be about the same, and each could supply a discharge of 20 liters or 5 gallons per minute for 10,000 years.

Hot Springs with Connate Water

The analyses of two hot spring waters believed to be dominantly connate in origin are shown in Table 5. Wilbur Springs, California, has a maximum surface temperature of about 60°C. and Tuscan Springs, California, a maximum of about 30°C. Mercy Springs, California, is also believed to be connate in part, but rather extensively diluted by meteoric water. The combination of high salinity and low temperature are the characteristics that first interested the writer in Wilbur Springs and that led to the present conclusions.

In spite of their relatively low temperatures, these saline springs could conceivably be volcanic if: (1) they are young enough, and flow through cool rocks that have not yet been heated extensively, or (2) they are cooled by mixture with enough cold meteoric water, or (3) their discharge is so small that most of the heat is carried off by normal rock conduction. Relative youth is an unlikely explanation, at least for Wilbur, because the springs are closely associated with mercury deposits (Waring, 1915, p. 99–106; White 1955, p. 130–132) that apparently are not forming now but probably were formed in Quaternary time. The high salinity and great excess of sulfide over sulfate argue strongly against cooling by extensive mixture with meteoric water.

The rate of discharge of saline water at Wilbur Springs and within ⅓ mile of the resort

is relatively small (about 40 gpm, computed to chlorinity of main Wilbur Spring) as compared to Steamboat Springs (about 700 gpm including subsurface discharge from the system). Because of great differences in salinity, however, the discharge of chloride at Wilbur Springs is about 1.7 kg per minute or 70 per cent of the 2.5 kg that is discharged at Steamboat Springs. The drainage area of Sulphur Creek above Wilbur Springs discharges additional water that is at least twice the total quantity of Wilbur, calculated to the same chlorinity. At least 6 kg per minute of chloride from water similar to that of Wilbur is discharged from a total drainage area of 25 km^2.

The flow of heat accompanying the discharge of water at Steamboat Springs is about 7×10^6 cal./sec., which is equivalent to the normal flow of heat from 600 km^2 of the earth's surface (White, 1957). This heat flow, from an area of about 5 km^2, is 120 times the "normal" flow (Birch, 1954). Only the heat contained in water above the mean annual temperature is included in these calculations.

The only obviously abnormal flow of heat in the Sulphur Creek area is in the water of Wilbur and other similar springs, which flow from rocks of the Knoxville Formation of Upper Jurassic age, adjacent to or near serpentine intrusions. The springs are not particularly gaseous and, because of the low temperatures, relatively little heat is lost in steam or water vapor, or by rock conduction. The flow of heat above the mean annual temperature in the discharging water is about 4×10^5 cal./sec. from 25 km^2, which is nearly equivalent to what the "normal" flow of heat by conduction should be from the same area (3×10^5 cal./sec.). The geothermal gradient is no doubt somewhat above the normal gradient; the total heat flow, including that of flowing water and rock conduction, is probably 3–5 times the "normal" for an area of this size but falls far short of the 120 multiples of "normal" flow from the 5 km^2 area of Steamboat Springs. The very abnormal heat flow at Steamboat must be explained as volcanic heat (White, 1957), but the slightly abnormal flow at Wilbur Springs appears explainable by the upflow of moderately heated water of non-volcanic origin.

The analyses of Wilbur and Tuscan Springs are similar to oil-field brines in a number of respects (Tables 1, 4, 5). The high iodine content of Wilbur and near-by springs has been recognized for many years (Watts, 1893; Waring, 1915, p. 102, 105), and Tuscan Springs is now known to be enriched in iodine. Both spring groups are also high in ammonium, in the ratio of sulfide to sulfate, and low in potassium and lithium relative to sodium. These chemical characteristics are believed to point strongly to a connate rather than a volcanic origin, supporting the evidence of heat flow. The similarity in composition between the waters of Wilbur Springs and the oil-test well 1 mile southeast of Wilbur is apparent (Tables 1, 5). Inflammable gases, presumably largely methane, accompanies the Tuscan waters (Waring, 1915, p. 289) and hot springs in the Wilbur Springs area (Watts, 1893, p. 182–183). In addition, isotopes of the waters of Wilbur and Tuscan are similar to those of Texas oil-field brines, according to Harmon Craig (personal communication). The quantities of some other components, such as the relatively high silica and low calcium, suggest a relation to volcanic hot springs. The boron content of Wilbur and Tuscan waters is higher than for any oil-field brine known to the writer, but the boron-chloride ratios are very similar to that of the Rio Vista gas-field brine. The bicarbonate content of Wilbur is exceptionally high, and some other components fall within the known ranges of both connate waters and volcanic hot springs.

The characteristics of Wilbur and Tuscan Springs are best explained by a dominantly connate origin. The differences between these spring waters and known oil-field brines may be explained in three ways: (1) Enough volcanic water is also present to account for the differences in characteristics, but not enough to affect the heat flow drastically. (2) Connate water, in changing from ocean water to oil-field brine, is approaching the composition of volcanic water in many respects as organic compounds decompose and as minerals, such as clays, are reconstituted and release adsorbed ions. Some of these changes have progressed a little further in the Wilbur and Tuscan waters in most oil-field brines. The high silica content of Wilbur may be due to the relatively high temperature of the source environment or to contact with rocks such as serpentine that may react readily to release monomeric silica. (3) As indicated below the exceptionally high bicarbonate and boron content suggests the presence of some metamorphic water. The writer favors the latter possibility, although the presence of a small percentage of volcanic water mixed with dominately connate water cannot be disproved by present evidence.

Many other springs are believed to be connate, at least in part. Bad Hall in Austria

TABLE 5.—ANALYSES OF THERMAL WATERS BELIEVED TO CONTAIN WATER OF CONNATE OR METAMORPHIC ORIGIN

(In parts per million)

	Wilbur Colusa Co. California[1]	Tuscan Tehama Co. California[2]	Mercy Fresno Co. California[3]	Bad Hall Austria[4]	Skaggs Sonoma Co. California[5]	Aetna Napa Co. California[6]	Sulphur Bank Lake Co. California[7]
Temp. °C.	57	30.1	45.8		54½	22	57
pH	7.24	8.3	8.6		7.2	8.1	
SiO_2	190	99	75	8.9	74	97	86
Fe		0.7[8]		6.1			0
Al	1[8]	1[8]		Tr.			
Ca	1.4	22	43	245	14	24	11
Mg	58	17	nil	156	5.4	72	0
Ba	1[8]	<4[8]					
Sr	10[8]	14[8]	9.3	13.0			
Na	9140	8080	830	6460	912	328	1550
K	460	51	7.1	10.4	33	6.0	50
Li	14	2.0	0.13	2.3	0.46	0.3	
NH_4	303	59	4.9	52		0.2	507
As	0.0						0(?)
Sb	0.0						0(?)
CO_3	0	103	31		0	0	0
HCO_3	7390	1150	13	425	2480	1060	3830
SO_4	23	67	5	0	6.5	0.5	119
Cl	11,000	11,800	1300	10,700	58	143	741
F	1.1	4.8	0.4		8.0	0.6	
Br	15	nil(?)	nil(?)	78		0(?)	Tr.
I	16	5.0	20	39		0.7	1.4
NO_3		0	0.5		0.5	2.1	
NO_2				0.03			
B	293	201	10	41	92	36	720
H_2S	178	185			0		Present
CO_2				26			
[9]Sum	29,100	21,900	2350	18,200	3680	1770	7620

H_2S	178	185			92	36	720
CO_2					0		Present
Sum	29,100	21,900	2350	26 18,200	3680	1770	7620
Ratios by wt.							
HCO_3[9]/Cl	0.67	0.11	0.059	0.040	43	7.4	5.2
SO_4/Cl	0.0021	0.0057	0.004	0.00000	0.11	0.003	0.16
F/Cl	0.0001	0.00041	0.0003		0.14	0.004	
Br/Cl	0.0014	<0.0001 (?)	<0.0001 (?)	0.0073		(<0.01)	<0.001
I/Cl	0.0015	0.00042	0.015	0.0037		(0.005)	0.0019
B/Cl	0.027	0.017	0.0077	0.0038	1.6	0.25	0.97
K/Na	0.050	0.0063	0.0085	0.0016	0.036	0.018	0.032
Li/Na	0.0015	0.00025	0.00016	0.00036	0.0005	0.0009	
Ca + Mg/Na + K	0.0062	0.0048	0.051	0.062	0.020	0.29	0.0069

[1] Mainspring (No. 22 of Waring, 1915, p. 102). Collected by White, August 3, 1949, analyzed by W. W. Brannock, U. S. Geological Survey. Density, 25°C., 1.016. Br and I determined in sample collected June 30, 1951.

[2] Largest flowing spring, collected by White, June 9, 1954; rises in large concrete tank (Waring, 1915, p. 290–291). Analyzed by H. Kramer and H. Almond, U. S. Geological Survey; contains 0.3 ppm Cu by spectrographic determination.

[3] Main Spring (Waring, 1915, p. 78–79). Collected by White, June 13, 1955, analyzed by H. Almond and S. Berman, U. S. Geological Survey.

[4] Guntherhöhen spring. Schmölzer, 1955. Also contains traces of Mn and Cu. May be nonthermal.

[5] Middle of 3 principal springs, collected by D. F. Hewett, August 20, 1953, analyzed by R. N. Martin of U. S. Geological Survey. Li from sample collected by White, from upper spring January 15, 1954 and analyzed by H. Kramer; latter also contained 0.2 ppm Fe, 0.1 Al, 0.01 Mn, 0.02 Cu, 1.0 Sr, 0.007 Cr, and only 0.04 Li by spectrographic determination.

[6] Soda spring, sec. 1, T. 9 N., R. 6 W. Collected by Calif. Division of Water Resources, May 3, 1955, analyzed by J. J. Popper, U. S. Geological Survey. Hotter (35° C.) and more highly mineralized water (1850 ppm HCO_3, 292 Cl, and 78 B) occurs in the shaft of an old quicksilver mine at the Aetna resort, but analyses are less complete (Waring, 1915, p. 156–159).

[7] From diamond drill hole supplying water to bathhouse. Collected by C. P. Ross, October 1938, analyzed by M. Fleischer, U. S. Geological Survey. Br and I from 1863 analysis (Whitney, 1865, p. 99–100).

[8] Spectrographic analysis.

[9] All carbonate and bicarbonate calculated as HCO_3.

(Schmölzer, 1955) is an example (Table 5). It is not clear whether these springs are cold or slightly thermal but Schmölzer believes their high iodine content indicates a connate origin.

Other analyzed springs (Waring, 1915, unless noted) with many or most of the chemical aspects of connate water are: Byron, California (p. 110–111); Fouts, California (p. 207); Neys, California (p. 265); Richardson, California (p. 292); Alhambra, California (p. 294); Complexion, California (p. 298); Tolenas, California (p. 163); Clifton, Arizona (Hem, 1950, p. 82); Saratoga, New York (Strock, 1941, p. 857); Kuan-Tsu-Ling, Formosa (Pan, 1952); Kwanshirei, Formosa (Ishizu, 1915, p. 162); Hamman Lif, Tunisia (Berthon, 1927); Bad Hamm, Germany (Himstedt, 1907, p. 163); Arima, Japan (Ikeda, 1949, p. 363); Debrecen and Hajdu-szoboszlo, Hungary (Papp, 1949, p. 300); and springs in Turkmenian Russia (Smolko, 1932).

Hot Springs with Metamorphic Water

No natural water has been proved to originate from sediments as a result of progressive metamorphism, although the almost universal decrease in water content with increase in grade of metamorphism demands the existence of migrating water of this origin. Little attention has been given in the past to metamorphic water, or to criteria for its recognition. It presumably escapes very slowly from rocks that are being progressively metamorphosed, and no doubt ordinarily mixes with large proportions of meteoric and connate water in overlying rocks. All geologists are familiar with old metamorphic rocks that are now revealed after extensive erosion of the original cover, but very little thought has been given to the probability that metamorphism is now taking place at depth in some parts of the world.

Many springs described by Waring (1915, p. 155–249) have compositions that are similar in part to connate water but are very high in combined CO_2 and commonly in boron, with relatively low chloride. Their temperatures, with few exceptions, are less than 60°C., and are always less than boiling. Many are in the California Coast Ranges north of San Francisco, and issue from or near rocks of the Franciscan group. The springs show a considerable range in composition but also have some features in common. As examples, analyses of Skaggs, Sulphur Bank, and Aetna springs are included in Table 5. All three springs are closely associated with mercury deposits (White, 1955, p. 117–120, 125, 130).

The isotopes of the water of Sulphur Bank are almost identical to those of Wilbur and Tuscan Springs (Harmon Craig, personal communication). The Sulphur Bank water is so different from the near-by Clear Lake water that it can have little admixed meteoric water.

The dissolved solids of these springs consist for the most part of sodium bicarbonate; HCO_3/Cl ratios are exceptionally high for known connate or volcanic waters. The boron-chloride ratios are among the highest of all analyzed waters. The few springs of this type that have been analyzed for ammonium and nitrate are relatively high in combined nitrogen.

Can these waters be at least in part of metamorphic origin? It is reasonable to suppose that, as sedimentary rocks are compacted and progressively metamorphosed, connate water high in chloride is first driven off. As the ratio of interstitial water to originally combined water decreases, the content of chloride in the escaping water may also decrease, because chloride is not abundantly adsorbed on clays and is rare in other hydrous minerals. When these minerals are recrystallized to minerals with lower water content or to anhydrous minerals, water with relatively little chloride is presumably freed.

With sufficient metamorphism, quartz combines with carbonates to form silicates and releases CO_2 (*See*, for example, Urey, 1956 p. 1126–1127). It is reasonable to suppose that some metamorphic waters, therefore, are high in CO_2 and in HCO_3/Cl ratios. James (1955, p. 1462, 1484–1485) indicates that the reaction between dolomite and quartz has produced some tremolite in the upper part of the biotite zone of metamorphism at a temperature that he concludes is close to 200°C. Where silicates are formed in the presence of only a little water, a CO_2-rich vapor phase or two fluid phases, one very high in CO_2, may form. At low temperatures where the associated water is below its boiling point, the reaction of carbonate and silica may take place to a limited extent until the water is saturated with CO_2. Conceivably, this could even occur in the low-grade metamorphic zones, but limited so much by the solubility of CO_2 that it has not been recognized. Another possibility is the reaction of carbonate and silica to form minerals such as prehnite and laumontite, and CO_2 in very low-grade metamorphic zones (Fyfe, 1955).

Little is known of the geochemistry of boron

in metamorphic rocks, or of the possibilities for enrichment of boron in metamorphic waters. Boron is greatly enriched in argillaceous marine sediments and ranges from about 15 to 300 ppm (Goldschmidt, 1954, p. 285), as compared with average igneous rocks, which contain only about 3 ppm (Rankama and Sahama, 1950, p. 226; Goldschmidt, 1954, p. 281). If many igneous rocks are formed by melting or partial fusion of sediments, as numerous geologists believe, most of the boron must be driven off before final crystallization. Although much boron may be evolved in the recycled magmatic water, it is reasonable to suspect that a large part could be driven off at an earlier stage in metamorphic water. This hypothesis remains to be tested by future geochemical studies.

Data on the boron content of glassy volcanic rocks (Coats, 1956, p. 76) and of thermal waters (some data supplied by D. F. Hewett of the U. S. Geological Survey) suggest that California, western Nevada, and southern Oregon constitute a high-boron province. If this is a fact, metamorphic waters in other parts of the world may not be characterized by boron-chloride ratios as high as in the California waters that have been described.

H. E. LeGrand of the U. S. Geological Survey (personal communication) has wisely suggested that a word of caution be added here. Care should be taken to guard against classifying many puzzling waters as metamorphic because no more obvious explanation is apparent.

Thermal Waters of Mixed Origin

It is assumed in the previous discussion that any of the deep waters may contain from negligible to high proportions of meteoric water but are still characterized chemically and identified by the deep components. Many other combinations of mixture are possible—deep waters with each other, with water immediately from the ocean by subsurface circulation, or with meteoric water that has come in contact with salt-bearing sediments.

A large number of thermal springs are relatively low in dissolved solids (1500 ppm or less) and differ appreciably from near-by meteoric waters. The waters may be almost entirely meteoric in origin; they perhaps contain traces of highly mineralized water of deep origin that have modified the composition only enough to make it unrecognizable, or additional mineral matter may have been leached from rocks.

There is, therefore, much danger of oversimplifying the problems of identification. This paper is a preliminary attempt to recognize some of the outstanding genetic types of ground water.

Conclusions and Speculations

Tentative criteria are proposed to distinguish waters of different origins; the results may be of significance for many fields of geology. For example, the ground water supply of many areas is threatened by salt-water encroachment. In coastal areas, the two principal possibilities are the direct invasion of sea water, and connate water from marine sediments. These two types should now be clearly distinguishable in many circumstances.

Probably all changes that occur in rocks—from diagenetic to metamorphic changes—are reflected in the compositions of the interstitial waters. The ability to correlate and to interpret these changes is still in its infancy. Direct economic applications of this principle are likely to appear first in the search for petroleum. The major components of oil-field brines have been of some interest in the past, but the minor components have been largely overlooked. Local differences in chemical and isotopic compositions of oil-field brines must be significant, but ability must be developed to interpret these differences in terms of the history and associations of the waters.

Many economic geologists assume that ore deposits are formed from hydrothermal solutions, and that these solutions are magmatic in origin. The present work indicates that hydrothermal solutions of many different origins may be transporters of ore. An important field for future research is to analyze chemically and isotopically the fluid inclusions of ore and gangue minerals for components that are likely to indicate the origin of the water and probably also of the ore components.

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U. S. Geological Survey, Menlo Park, California
Manuscript Received by the Secretary of the Society, March 26, 1957
Publication Authorized by the Director, U. S. Geological Survey

Short Notes

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 68, PP. 1683-1688, 3 FIGS., 1 PL. DECEMBER 1957

HYPOTHESIS REGARDING THE ORIGIN OF THINOLITE TUFA AT PYRAMID LAKE, NEVADA

BY DOROTHY H. RADBRUCH

Introduction

Several forms of calcium-carbonate tufa are exposed in the desert basins of Nevada that were formerly occupied by Lake Lahontan. One of these forms is thinolite, which consists of delicate elongate skeletal crystals, most of which are terminated at both ends by pyramids. The skeletal crystals are made up of many small calcite crystals. The thinolite crystals have been well described in previous publications by Clarence King (1878), E. S. Dana (1884), I. C. Russell (1885), and J. C. Jones (1925). The mode of origin of the thinolite tufa has long been a topic for speculation; a possible mode of origin is suggested in this paper. No attempt is made here to present an exhaustive study of thinolite; the purpose of this paper is to present a tentative idea, with the thought in mind that further work may clarify the problem of origin of the tufas of Lake Lahontan.

Previous Work

The tufas of Lake Lahontan were first described by Clarence King (1878) in the Geological Exploration of the 40th Parallel. He submitted samples of the thinolite crystals to E. S. Dana, who thought that thinolite might be a pseudomorph after gaylussite ($Na_2Ca(CO_3)_2 \cdot 5H_2O$). King described it in his report of the exploration (p. 519) as "... a pseudomorph of carbonate of lime after gaylussite ... formed in the highly carbonated alkaline solution; the pseudomorph being a subsequent result of the addition of calcareous matter to the solution, the lime replacing the carbonate of soda of the gaylussite, and transforming it into carbonate of lime." A very saline solution was thought necessary for the formation of the thinolite; however, the present lakes are not as saline as would be expected from evaporation of such a concentrated solution. King postulated that a flood period followed deposition of the thinolite, and the fresh flood water replaced the saline solution. The new lake must then have been in very delicate chemical balance, so that the solution contained "... lime enough for the pseudomorph, and yet carbonate of soda enough to prevent the re-solution of the gaylussite" (p. 521). Although King applied the term "thinolite" to all the tufas, Russell (1883) redefined it to mean only the tufa having the typical elongate skeletal form and classed the other types as "dendritic" or "lithoid".

In 1884 Dana published a detailed study of the thinolite, in which he considered it in the restricted sense, as defined by Russell. On the basis of the crystal form, Dana concluded that the thinolite crystals were not originally gaylussite, as was first thought, but may have been an unknown double salt, perhaps a chloro-carbonate of calcium. He suggested that the original mineral was the same as that which formed isolated crystals in the Sangerhausen clay and the Kating marl. I. C. Russell (1885), in his monograph on the geologic history of Lake Lahontan, quoted Dana's findings.

In 1925, J. C. Jones made extensive studies of the thinolite crystals. After measuring many crystals with the goniometer, he concluded that the original mineral forming the thinolite was probably aragonite. He found that when a saturated solution of calcium carbonate was added to water from Pyramid Lake and allowed to stand for several days, minute crystals of aragonite, which resembled the thinolite, formed. He therefore concluded that the thinolite was probably deposited from water that was almost saturated with calcium carbonate, and that most of it formed on tufa with which the water was in contact. He suggested (p. 24) that the scattered crystals of thinolite that he found in clays of terraces of the Smoke Creek Desert "... may have separated spontaneously from the lake water and fallen to the bottom."

Description of Thinolite

In this paper the name "thinolite" is used in the restricted sense, and applies only to the tufa having the typical elongate skeletal habit. In its most common form, thinolite is an elongate skeletal crystal roughly square or rectangular in cross section, consisting of a prism terminated at both ends by pyramids. The faces tend to be curved convex outward, and the edges between prism and pyramid forms are rounded.

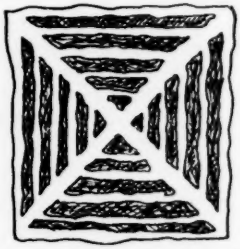

FIGURE 1.—GENERALIZED CROSS SECTION OF A THINOLITE CRYSTAL

In cross section the crystal seems to consist of a number of concentric hollow rectangles connected by diagonal septa which pass through the corners of each rectangle (Fig. 1). The entire crystal, when viewed from the side, is seen to consist of many hollow pyramids, each one nested inside the one above it, so that the rough surface of the crystal is made up of overlapping, roughly parallel plates (Fig. 2). Individual crystals range in length from an eighth of an inch to more than 12 inches.

In thin section it is seen that the so-called crystal is not a single crystal at all, but that the delicate septa and hollow pyramids forming the crystal are themselves made up of many small calcite crystals. The calcite crystals appear on cursory examination to be unoriented, although Dunn (1953, p. 21) reports that a petrofabric examination of thinolite from Mono Lake shows that "... the c-axes of the calcite were aligned normal to the elongation of the 'prisms' of thinolite."

Present Investigation

Thinolite occurs around Mono Lake and in several places in the basin of former Lake Lahontan, especially around Pyramid and Winnemucca Lakes. Recent lowering of the water level of Pyramid Lake has exposed deposits of thinolite that have not previously been described. It was the finding of thinolite apparently in place in recently exposed fresh muds along the shore of Pyramid Lake that gave rise to the present study. Exposures along the shore of the lake were examined several times in 1954, 1955, and 1956.

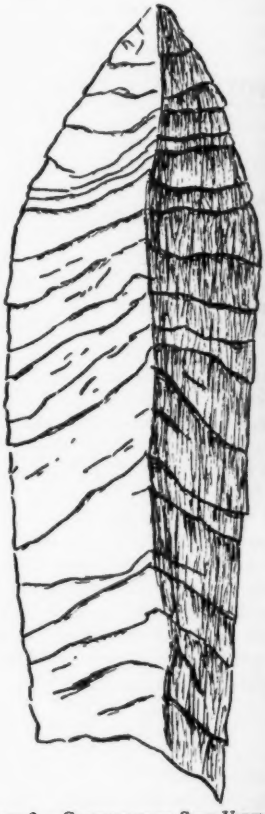

FIGURE 2.—GENERALIZED SIDE VIEW OF A THINOLITE CRYSTAL

Pyramid Lake is approximately 35 miles northeast of Reno, Nevada (Fig. 3). It is one of the few remnants of old Lake Lahontan, and in 1954 was about 30 miles long, 8–12 miles

PLATE 1.—THINOLITE ON WEST SIDE OF PYRAMID LAKE, NEVADA

FIGURE 1.—Thinolite crystals projecting from mud along shore of Pyramid Lake.
FIGURE 2.—Broken fragment of tufa dome, showing thinolite crystals from inside of dome.

FIGURE 1

FIGURE 2

THINOLITE ON WEST SIDE OF PYRAMID LAKE, NEVADA

wide, and 330 feet deep at its deepest point. In 1844, when Fremont (1845) visited the lake, its surface was about 3860 feet in altitude (Hardman and Venstrom, 1941). In June of 1954, the surface of the lake was 3807.03 feet in altitude (C. H. Carstens, personal communication). Sutcliffe, approximately on the township line between T. 25 N. and T. 24 N., R. 21 E., Mount Diablo Base Line. This spot can easily be reached from the road that follows the west shore of the lake, which at this point is about one-third of a mile west of the shore line.

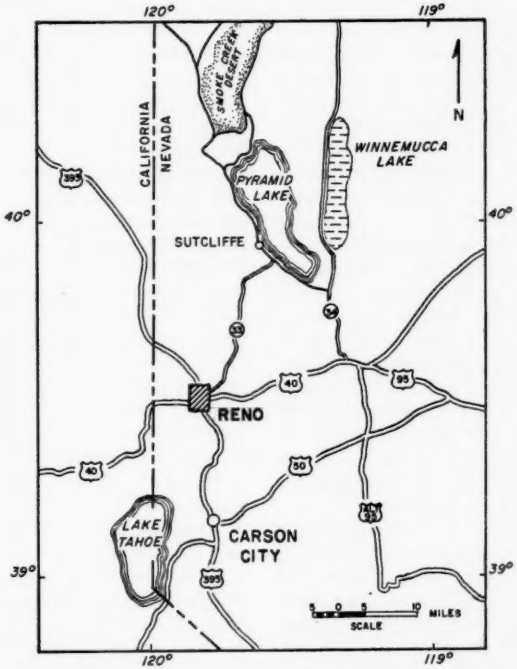

FIGURE 3.—INDEX MAP SHOWING LOCATION OF PYRAMID LAKE

Most of the recent lowering of lake level is due not to gradual drying up of Lake Lahontan, but to the flow of water into Pyramid Lake being diminished by removal of irrigation water from the Truckee River, which feeds the lake. Since 1907, removal of water from the Truckee River has caused the lake to drop rapidly. In 1905 the water level of Pyramid Lake was 3867 feet (Hardman and Venstrom, 1941); by 1954 it had dropped 60 feet.

This lowering of the lake surface has exposed a wide strip of land along the shore that was under water when King, in 1878, Russell, in 1885, and Jones, in 1925, studied the area. Within this band of newly exposed shore, fresh mud deposits containing thinolite have been found in several places. The most extensive deposit seen by the author lies on the west shore of the lake, about 3 miles north of the town of

At this locality several large tufa domes, about 20 feet high, stand approximately 20 feet back from the water's edge. At the edge of the water is a gently sloping mud flat, from 2 to 10 feet wide, and about 900 feet long, broken here and there by smaller tufa domes and masses of broken tufa. On either side of the mud flat the beach consists of sand and gravel, much of which is broken pieces of thinolite.

At numerous places in the mud, isolated crystals or clusters of crystals of thinolite are visible (Pl. 1, fig. 1). Most of the crystals stand upright in the mud; their long axes are perpendicular to the sloping surface of the mud, so that they are all oriented with their long axes slightly tilted. The upper ends of the crystals, which project a few inches above the surface of the mud, are firm and contain numerous well-formed septa. The points of the hollow pyramids

forming the crystals all point upward. The individual crystals or groups of crystals become more fragile and skeletal toward their lower ends, and at a depth of approximately 18 inches below the surface of the mud a slight "gritty" feel to the mud marks the lower limit of the thinolite deposits. Below this depth only mud is found.

The tufa domes that rise west of the shore are circular in plan, and many of them have flat depressions in the top, some as much as 15 feet across. Some of the domes have been split and eroded, so that a good cross section of their interior can be observed.

In some of the broken domes a hard interior core, or an older interior dome, can be seen, surrounded by mud and thinolite. The soft mud, which may be dry or slightly damp, contains very little thinolite near the core, but outward from the core it contains delicate, skeletal crystals, which become harder and denser toward the exterior of the dome, until no mud, but only a mass of thinolite crystals remains. The crystals are oriented with their long axes radiating outward from the center of the dome, and the tops of the hollow pyramids that form the crystals point outward. A dense outer covering of fine-grained, banded tufa about 6 inches thick coats the outside of the domes.

In some places the domes have cracked and fallen apart, so that broken pieces of the domes lie upside down near the upright domes; the hard outer curved covering rests on the ground, and the thinolite crystals radiate from a peak at the top of the large fragment (Pl. 1, fig. 2); these broken pieces in some places have been covered with another layer of dense, calcareous material.

Near the Pyramid, on the east side of the lake, similar domes were observed. In one place a small dome contained a few thinolite crystals radiating outward from the center, which was filled with soft mud. Although no water or gas was observed escaping from the dome, several small craters such as would form by the escape of gas through mud were preserved in the soft, wet mud; they must have formed there very shortly before they were observed, in order for them to be so well formed and undamaged by erosion.

Mode of Origin of the Crystals

The uniform and consistent orientation of the crystals that stand perpendicular to the sloping surface of shore-line mud, or perpendicular to the outer surfaces of the tufa domes, indicates that the crystals formed in place and were not washed into the position they now occupy. Neither does it seem likely that the crystals could have formed in place and then been surrounded by mud.

If mud were washed in around crystals in the dome, it would logically have been washed down from the top, or deposited around the sides. The fact that the mud is not in the outer part of the domes, or only at the top, but on the inside, suggests to the writer that the crystals formed in mud, growing from the outside in, rather than that mud washed in around a dome consisting of already-formed crystals.

If mud were washed in around crystals that are now in the mud flats along the shore of the lake, this would require that the long, thin, isolated crystals, which become more delicate and eventually disappear downward into the mud, formed in some manner presently unknown, stood upright on their ends at an angle and then, after they were surrounded by mud, had their lower ends partially dissolved. This supposes either that the single crystals stood for some time in a position that would be extremely difficult to maintain against gravity and wind or wave action, or that they are remnants of a former large mass of crystals.

When the deposit of thinolite along the west side of Pyramid Lake was visited in the spring of 1956, it was found that owing to the heavy winter and spring precipitation and to the large amount of water being discharged into the lake by the Truckee River, the level of the lake had risen, and much of the mud along the shore, and the thinolite in it, had been cut away by the rising water. None of the thinolite crystals remained standing after the mud had been washed away; they lay along the edge of the water, in a broken and jumbled mass. Single upright skeletal crystals of thinolite, therefore, could probably not survive even gentle wave action, but would quickly be broken and washed away.

If the upright crystals in the mud were the remnants of a former large mass of crystals that has been dissolved, it would be reasonable to suppose that bits of the rest of the mass would be in the mud around the single crystals, or that the sides of the single crystals would grade into the mud, as do the bases of the crystals. None of this is true. The sides of each isolated crystal are firm and well defined and have no gradation or evidence of re-solution around the edges. In fact, the reverse is true; as the crystals become more solid, they tend to

fill in from the outside in, so that the outer part of the crystal is firmer than the inner part, which remains more skeletal.

The muds along the shore of the lake that contain thinolite are very calcareous and effervesce vigorously when placed in dilute hydrochloric acid. A sample of the mud from the west side of Pyramid Lake, after treatment with dilute hydrochloric acid, lost 60.4 per cent of its weight; most of the material lost was probably calcium carbonate.

It seems probable that much calcium carbonate is deposited when waters of springs mingle with the alkaline waters of the lake. Numerous springs discharge into the lake, particularly in areas where tufa domes are abundant. Both Russell (1885, p. 60) and Jones (1925, p. 14) report that calcium carbonate deposits formed around the orifices of springs discharging into the lake, and many of the tufa domes were probably built up in this manner. No doubt much of this calcium carbonate mingles with argillaceous sediments in the lake to form calcareous muds, particularly in areas where springs are active. Calcareous muds may have formed in this manner in the past, and up to the present time.

In view of the above observations, it is suggested that the thinolite crystals or their antecedent crystals were not precipitated directly from the water of Lake Lahontan, but that they formed in fine, calcareous muds inside tufa domes, or as isolated crystals in bottom sediments.

Unresolved Questions Regarding Origin of Thinolite

Some of the questions that remain unanswered are:

(1) How did the mud in which the crystals formed get inside the tufa domes? Two possibilities may be considered: that the mud was drawn up into the domes by a "pumping" action of springs, or that the crystals formed in the mud by depositing around a nucleus, and the outer "rind" of the dome formed later around the crystals, by direct precipitation from the water, algal action, or some other means. Not enough data have been accumulated by the writer to show conclusively how the mud came to be inside the domes.

(2) Are the crystals pseudomorphs after a former mineral, or did they deposit in their present form, and at what stage in the history of Lake Lahontan were they deposited? The writer believes that the crystals deposited in their present form, and that they deposited throughout much of the history of Lake Lahontan up to the present time. This opinion is based on the fact that isolated crystals are found in muds that are apparently of quite recent age, and that particles of mud and ostracods from the mud are found inside the crystals, in the interstices between the septa, where they were apparently enclosed within the crystal as it formed. Because the mud and ostracods could possibly have entered the interstices through some breaks in the crystals, however, this evidence is not regarded as conclusive. Moreover, at this time the writer can present no chemical or mineralogical evidence or theory to explain the reason for the unusual form of the thinolite, or the fact that each thinolite crystal is composed of minute calcite crystals.

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U. S. Geological Survey, Menlo Park, California

Manuscript Received by the Secretary of the Society, March 25, 1957

Publication Authorized by the Director, U. S. Geological Survey

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 68, PP. 1689-1692, 1 FIG. DECEMBER 1957

COMPARISON OF TWO- AND THREE-DIMENSIONAL SPHERICITY OF SAND GRAINS

JOHN BOKMAN

Introduction

In a recent paper in this Bulletin, Curray and Griffiths (1955) describe a statistical study of the intercept sphericities of 2700 loose quartz grains. These were selected to form a nested sampling design based on grains, samples, formations, and rock types. Means and variances were determined for three common sandstone types, for four size grades, and for the overall population. No consistent relation was found between size and sphericity, and although small differences in sphericity existed between rock types they were shown to be statistically not significant.

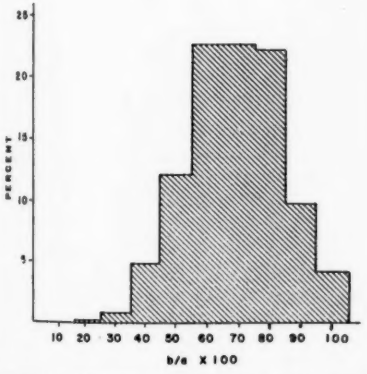

FIGURE 1.—HISTOGRAM SHOWING DISTRIBUTION OF AXIAL RATIOS ($b/a \times 100$) OF 12,737 SAND GRAINS

The writer had at his disposal a large number of measurements of sand grains in thin section, and a reading of Curray and Griffiths' paper suggested a comparison of the two sets of data. Such a comparison would determine the accuracy with which the mean two-dimensional axial ratio of a sample of grains estimates the mean three-dimensional sphericity. This would be of value in thin-section studies, in which the true sphericity cannot be directly determined.

Description and Summary of Data

The axial (b/a) ratio of a projected grain image is the ratio between the minimum cross-sectional axis and the axis at right angles thereto. This was measured by means of a plastic template laid over grain images projected from thin section onto a light table.

The total population consists of 12,737 b/a ratios. These are grouped into 19 samples (formations) composed of between 279 and 854 grains each (average 670). The formations represented range in age from Devonian to Recent and are orthoquartzites and low-rank graywackes.

The data are tabulated in Table 1 and Figure 1. The total number of grains is summarized by formation and by shape class; the weighted sum (frequency $\times$ shape) is also recorded for each formation and for the overall total. The grand ($b/a \times 100$) mean for all grains is $X = 68$, and the variance of all grains around this mean is 226. The 19 individual formation averages range from 64 to 73 with a variance of 5.8.

Discussion

The mean sphericity of all grains given by Curray and Griffiths is $\bar{X} = 75.18$, and the variance is $s^2 = 69.52$. The differences between these values and those given above for the distribution of axial ratios probably reflect a difference in the nature of the populations. The sphericity measured for the loose grains is a function of all three grain axes (Krumbein, 1941, p. 70–72). On the other hand, thin sectioning a great many grains produces cross sections with axial ratios proportional to all possible pairs of the three axes and intermediate radii. A certain number of these values are less than the true sphericity of any grain present; a greater percentage of low axial ratios also are produced than are present in the corresponding sphericity classes. This shift in the distributions is shown in Table 2, which compares Figure 1 with Curray and Griffiths' Figure 3 (p. 1081).

The difference between the means of the axial ratio and sphericity distributions is 75 –

TABLE 1.—DISTRIBUTION OF AXIAL RATIOS OF SAND GRAINS

Grain Shape, Mid Point (b/a × 100)		Total	Atoka	Hardinsburg	Aux Vases	Cypress	Misener	Wilcox	Graneros	Berea	Dakota	Morrison	Recent (Mustang Isl., Texas)	Recent (Chenier, La.)	Belle Canyon	Recent (Holly Beach, La.)	Tertiary (So. America)	Recent (Topsail Beach, N. C.)	Recent (Grand Isle, La.)	Recent (Miss. River)	Recent (Padre Isl., Texas)
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20		20	0	0	0	0	0	1	0	0	0	0	2	1	1	8	3	0	2	2	0
30		109	1	4	8	4	1	10	0	1	6	9	12	9	7	5	9	5	4	9	5
40		664	37	18	36	18	17	49	17	24	12	51	24	41	64	35	52	18	49	70	32
50		1478	69	86	102	73	82	121	67	88	50	90	74	110	99	83	56	39	55	76	58
60		3026	212	161	184	153	193	159	164	189	132	156	116	224	211	176	109	59	105	204	119
70		2984	166	208	178	216	188	176	193	213	166	203	109	211	162	152	73	62	59	138	111
80		2739	214	154	150	165	141	142	158	147	189	155	71	174	177	214	65	50	82	204	87
90		1258	71	86	70	91	88	64	81	83	110	82	34	73	47	87	33	36	21	64	37
100		459	25	33	26	24	36	33	41	7	29	38	9	11	23	41	13	8	23	35	4
Total	No. of Grains	12,737	795	750	754	744	746	755	721	752	694	784	451	854	791	801	413	277	400	802	453
	Weighted Sum	872,810	5531	5290	5100	5258	5235	5061	5141	5157	5062	5400	2927	5723	5257	5601	2627	1878	2605	5435	2993
$\bar{X}$		68	70	70	68	71	70	67	71	69	73	69	65	67	66	70	64	67	65	68	66

TABLE 2.—COMPARISON OF SPHERICITY AND AXIAL RATIO DISTRIBUTIONS

Group Limits	Percentage of distribution	
	Sphericity	Axial ratio
<44	0	6
44–64	9	35
64–84	75	45
>84	16	14

68 = 7. This average value provides an approximate correction term which can be added to the mean axial ratio of a reasonably large number of sand grains to obtain the mean sphericity.

Acknowledgments

The measurements on which this paper is based were made by a number of people in addition to the writer: J. R. Curray, J. E. Emery, C. W. Wheeler, Virginia Minor, Robert Arndt, and P. M. Miller.

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MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, JUNE 6, 1957.

Bulletin

of

The Geological Society of America

VOLUME 68 December 1957 NUMBER 12 PART 2

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Subscription $15.00 per year.

Printing Office: Mt. Royal & Guilford Aves., Baltimore 2, Md.

Communications for publications should be addressed to The Geological Society of America, Dr. H. R. Aldrich, Secretary, 419 West 117 Street, New York, N. Y.

Please give notice of change of address 4 weeks in advance. Claims for nonreceipt of the Bulletin of a given month must be sent to the Secretary of the Society before the end of the second succeeding month.

Entered as second-class matter at the Post Office at Baltimore, Md., under the Act of Congress of July 16, 1894.
Accepted for mailing at special rate of postage provided for in Section 1103 Act of October 3, 1917, authorized on July 8, 1918.

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ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN ATLANTIC CITY, NEW JERSEY, NOVEMBER 4–6, 1957

THORIUM, URANIUM, AND POTASSIUM CONTENTS OF BAUXITES

John A. S. Adams and Keith Richardson
The Rice Institute, Houston, Texas

More than 20 samples of bauxites and bauxitic material from different localities in the world have been analyzed for thorium, uranium, and potassium by gamma-ray spectrometric, fluorometric-uranium, and alpha-activity methods. The following ranges of concentrations were found: 8 to 132 ppm thorium; 3 to 27 ppm uranium, and 0.00 to 0.30 per cent potassium (as metal). The median values were: 42 ppm thorium; 8 ppm uranium, and 0.10 per cent potassium. The median thorium content is about three times, and the median uranium content is about twice that found in average shale or average igneous rock. Experiments on a sample of Surinam bauxite indicate that much of the thorium and uranium is contained in resistate minerals like zircon and that very little uranium is carried over into commercial alumina and aluminum metal. There are some indications that thorium and uranium concentrations may reflect the grade of bauxite ore.

OSTRACODA FROM THE VINCENTOWN FORMATION IN THE COASTAL PLAIN OF NEW JERSEY

John K. Adams
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Twenty-five species of Ostracoda are recognized from the Vincentown Formation of New Jersey. Nine new species and one new variety have been identified. Seven of the 25 species have been described from the Aquia Formation of Maryland, Delaware, and Virginia. On the basis of this faunal similarity, the Vincentown and the Aquia formations appear to be correlative.

An examination of the uppermost Hornerstown Formation shows a much smaller fauna both taxonomically and numerically than the Vincentown. This faunal difference is considered to be a facies rather than a time difference. Parallel evidence is suggested by the Foraminifera which show different benthonic but similar planktonic species in the uppermost Hornerstown and in the Vincentown formations.

MINERALS IN LATERITES IN THE STATE OF BOLIVAR, VENEZUELA

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Geologists in Venezuela use the term "laterite" for three different types of materials: (1) siliceous or argillaceous laterite, (2) ferruginous laterite, and (3) aluminous or bauxitic laterite. Petrographic and differential thermal studies indicate that kaolinite is the principal clay mineral in the argillaceous laterite; that hematite, goethite, and limonite are the chief iron minerals in the ferruginous laterite; and that gibbsite, boehmite, and kaolinite are the chief alumina minerals in the bauxitic laterite. Argillaceous laterite is widely exposed at the surface and underlies many iron deposits in the state of Bolivar. At many localities it retains the structure and the chemically resistant minerals of the parent rock. Thus, it has the composition and characteristics of lithomarge, the clayey part of the lateritic profile in India. Ferruginous laterite is well represented at Cerro Bolivar, El Pao, and other iron deposits. Bauxitic laterite is limited in its occurrence but is present at El Chorro, near Upata. To avoid misunderstnading, the term "laterite" should not be used as a field term without appropirate qualification.

GEOLOGY OF WALNUT WELLS QUADRANGLE, HIDALGO COUNTY, NEW MEXICO*

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In this area 300 feet of Lower and Middle Permian fusulinid limestones has been thrust upon Lower Cretaceous sediments. The base of the latter is concealed, but 3000 feet of Nuevo Leon, Trinity, and Fredericksburg limestones with interbedded shale and sandstone has been measured, unconformably below 7200 feet of Fredericksburg and Washita orthoquartzites with interbedded sandy shales. Disconformably above is 1000 feet or more of Upper Cretaceous sandstones and limestone conglomerates.

More than 90 per cent of the area is underlain by Tertiary extrusives and intrusives, mostly silicic to intermediate in composition. Three main igneous phases are recognized and subdivided into 11 mappable units: (1) extrusion of quartz latite tuffs 5000 feet thick, and emplacement of two monzonite porphyry bodies; (2) after uplift and erosion, extrusion of hornblende latite and white rhyolite tuffs to a thickness of 1900 feet; (3) after renewed uplift and erosion, extrusion of latite tuff, 1000 feet thick. Probable ages are (1) Miocene to early Pliocene, (2) Pliocene, and (3) Pliocene to post Wisconsin.

Several cycles of deformation are distinguished. Pre-Tertiary rocks were deformed to open, eastward-trending folds, and Lower Permian limestones were thrust on Cretaceous sediments and folded. Later, Cretaceous sediments were deformed to tight, northward-trending folds and thrust to the southwest. Tertiary deformation is characterized by normal faulting striking roughly north. Movements along the faults were recurrent, and locally even alluvium was affected.

CHEMICAL ANALYSES OF THE INCLUSION FLUIDS IN A GROUP OF NEW MEXICO MINERALS

Lloyd L. Ames, Jr.
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The fluid inclusions in a suite of minerals from the Hansonburg and Derry districts, New Mexico, were analyzed for sodium, potassium, lithium, rubidium, cesium, aluminum, magnesium, copper, chlorine, and sulfate using the ball-milling technique of E. W. Roedder. Galena, barite, and fluorite crystals that grew in open solution cavities in limestone were selected to obtain only those fluids that contributed to original crystal growth. Silicification that preceded galena, barite, and fluorite deposition minimized the chemical influence of the limestone wallrock on depositing solutions. The Derry deposit is also fissure and solution-cavity filling in limestone but with fluorite as the only ore mineral.

Depositional sequence as indicated by the heated-stage method was fluorite, 90° to 100°C, and barite, 130° to 140°C. Galena preceded barite deposition.

Chemical analyses of the inclusion fluids show a steady decrease in the sodium-potassium ratio from 2.3 in the galena to 0.1 in the fluorite, indicating a continuity of mineral-depositing solution over the time and temperature range represented by the Hansonburg mineral suite. A chlorine content nearly five times as high in the galena inclusion fluids as in the fluorite and barite suggests at least partial transport of the lead in a chlorine complex.

Sodium-potassium ratios of 0.1 for both the Hansonburg and Derry fluorite inclusion fluids reflect similar depositional environments despite their spatial separation of about 90 miles.

Weight losses on these fluorite and barite samples indicate an average salt concentration in the inclusion fluids of about 25 per cent.

The geologic section and the deformation indicate that Laramide deformation of this thicker Mexican geosynclinal region of southwestern New Mexico preceded the deformation of central New Mexico.

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FACTORS AFFECTING MAXIMUM HYDROTHERMAL STABILITY IN MONTMORILLONITES

L. L. Ames, Jr. and L. B. Sand
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The relative importance of the factors affecting maximum thermal stability in montmorillonites in hydrothermal systems was investigated. The influencing factors considered were (1) interlayer cations, (2) composition, and (3) types of lattice substitutions.

The absence of an interlayer alkali (Na) cation gives low decomposition temperatures of about 300°C. for magnesium montmorillonites and 400°C. for aluminum montmorillonites as compared to 750°C. and 480°C., respectively, when the alkali is present to satisfy the excess negative charge. With optimum substitution, saponites have considerably higher maximum stabilities than the aluminum montmorillonites. Lattice substitutions (in all cases to give excess charge corresponding to maximum base-exchange capacity) in montmorillonites affecting maximum hydrothermal stability are as follows:

A. for aluminum montmorillonites
1. substitution of Al for Si in tetrahedral co-ordination

$$Al_2(Si_{3.67}\uparrow Al_{.33})O_{10}(OH)_2 \xrightarrow{Na_{.33},\ 480°C.} \text{paragonite, pyrophyllite, mullite}$$

2. substitution of Mg for Al in octahedral co-ordination

$$(Al_{1.67}\uparrow Mg_{.33})Si_4O_{10}(OH)_2 \xrightarrow{Na_{.33},\ 480°C.} \text{saponite, albite, cristobalite}$$

B. for magnesium montmorillonites
1. substitution of Al for Si in tetrahedral co-ordination

$$Mg_3(Si_{3.67}\uparrow Al_{.33})O_{10}(OH)_2 \xrightarrow{Na_{.33},\ 750°C.} \text{talc} \xrightarrow{780°C.} \text{enstatite, quartz}$$

2. substitution of Li for Mg in octahedral co-ordination

$$(Mg_{2.67}\uparrow Li_{.33})Si_4O_{10}(OH)_2 \xrightarrow{Na_{.33},\ 750°C.} \text{talc} \xrightarrow{780°C.} \text{anthophyllite}$$

A marked decrease in stability results when substitution in the lattice deviates from the optimum amount, although still retaining electrostatic balance by changing the amounts of other cations. For example, in the saponites: $Al_{.33}$ (750°C.), $Al_{.22}$ (680°C.), $Al_{.11}$ (350°C.), and $Al_{.00}$ (300°C.).

GENESIS OF SPILITIC ROCKS AND MINERAL DEPOSITS

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The comparison of approximately 250 occurrences of spilitic rocks has led to the following conclusions: Most rocks called spilites and/or keratophyres, and a great number of rocks of the same composition not yet called spilites, appear to be primary magmatic crystallization products rather than products of soda metasomatism, regional metamorphism, surface alterations, or sea-water soda diffusion.

While spilitic rocks show an almost ubiquitous distribution both in space and time, they are still a special rock type forming under special conditions. These conditions can be described as hydromagmatic and represent the hitherto little-recognized low-temperature low-pressure bridge between, and/or the combination of, common igneous rocks and hydrothermal mineral deposits.

A number of oligo- or monomineralic mineral deposits appear to be associated with spilitic hydro-

magmas. The similarity to pegmatitic and hydrothermal deposits (both in composition and sequence) and the association with spilitic rocks illustrate the fact that these mineral deposits are spilitic differentiation products which were deposited inside or close to the parent rock. They are thus usually syngenetic and belong to the group of volcanic mineral deposits of the Niggli-Schneiderhoehn classification.

NATURAL ARSENO-SULFIDE GLASS

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An arseno-sulfide glass forms the last generation in vugs in a few sphalerite ore bodies at Cerro de Pasco, Peru. It is reniform and/or exhibits tubules of 0.1 to 1 mm inner diameter and 0.5 to 90 mm length. The color varies from dull black to silvery gray to dark or, if fine-grained, bright red. It is translucent in small splinters, although less than artificial As-S-glasses. Its reflectivity is 30 per cent, and its Talmage hardness B. The orange lathey mineral often associated with the powdery red form of this glass conforms to the original description of the mineral dimorphite.

The chemical composition varies inside these boundaries:

$$Pb_{10\text{-}20\%}Tl_{\pm 1\%}As_{35\text{-}45\%}S_{35\text{-}45\%}.$$

More than 50 X-ray photographs of the original material, and of chemically and physically treated samples, showed no changes in the ring patterns typical for glassy substances.

The glassy state of sulfides can be visualized by a "snow-flake theory": the building stones consist of groupings of atoms (rings, chains, etc) similar in shape to portions of crystal lattices. Arranged in an orderly way, these "snow flakes" of As, S, etc., correspond almost to a crystal lattice. Inability of frozen-in "impurities" (Pb, Tl, etc) to assume an orderly array or to migrate, and/or deformations may be responsible for the glass formation.

Current laboratory experiments with natural and artificial sulfide glasses afford another new approach to the physical chemistry of hydrothermal mineral deposits.

CRYSTAL-CHEMICAL STUDY OF JOHANNITE

Daniel E. Appleman
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Re-examination of the crystallography of johannite by X-ray precession techniques yields the following data: triclinic, space group $P\bar{1}$; $a = 8.91$ Å, $b = 9.51$, $c = 6.81$; $\alpha = 109°42'$, $\beta = 112°07'$, $\gamma = 100°26'$; cell contents: $[Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O]$; specific gravity (calculated) 3.31, (observed) 3.32. Polysynthetic twinning is common, twin axis [001]. Johannite has been synthesized from aqueous solution at room temperature; good single crystals were obtained by slow cooling of supersaturated solutions in sealed tubes.

A crystal-structure analysis has been carried out with intensity data visually estimated from Weissenberg and precession films of the principal zones. The preliminary structure shows that each uranyl ion is co-ordinated by three oxygen atoms from different sulfate groups, and each sulfate group shares oxygen atoms with three uranyl ions; the endless double chains thus formed, parallel to [001], are apparently linked by pairs of $(OH)^-$ ions shared between two uranyl ions. The uranyl ion is thus in fivefold co-ordination. The resulting structure consists of infinite sheets parallel to (001), cross-linked by copper atoms bonded to the fourth sulfate oxygen. In the light of this structure, it is suggested that the precipitation which occurs at pH > 4.5 from aqueous solutions containing the weak uranyl sulfate complex may be due to the formation of hydroxyl linkages between uranyl sulfate groups, with consequent precipitation of basic uranyl sulfates having johannitelike structures.

REINTERPRETATION OF THE BANNOCK OVERTHRUST, SOUTHEASTERN IDAHO

Frank C. Armstrong and Earle R. Cressman
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The Bannock overthrust in southeastern Idaho and northeastern Utah was originally described by Richards and Mansfield as a single, large thrust fault formed at the close of the Laramide orogeny and folded by renewed compression at the end of Pliocene time. In later years their concept of at least the northern part of the Bannock changed to that of a thrust zone in which the individual faults originated in a folded sole thrust.

Detailed mapping in areas critical to Richards' and Mansfield's interpretation has shown that faults thought by them to be parts of one large thrust are separate faults, and that, although some of the thrust planes are slightly curved, they are not folded as originally postulated; the slight curvature of the thrust-fault planes is thought to be an original characteristic of the faults. Extensions of the Bannock thrust to the north, south, east, and west based upon extrapolation of the concept of a folded thrust plane are not warranted.

The Bannock overthrust is reinterpreted as an imbricated thrust zone possibly several tens of miles wide extending at least from southwestern Montana to northeastern Utah. It is recommended that the name Bannock overthrust, or Bannock thrust, no longer be used, and that Southeastern Idaho thrust zone be substituted for it.

APPARATUS FOR THE STUDY OF ELECTRON TRAPPING IN MINERALS

G. E. Ashby, R. C. Kellagher, and W. A. Chisholm
U. S. Geological Survey, Washington, D. C.

An apparatus has been constructed to record the thermoluminescence properties of a mineral in the form of a powder or single crystal at temperatures from −100°C. to +400°C. Glow curves are obtained by heating the sample at a constant rate and recording the intensity of the thermoluminescence as a function of temperature. The apparatus has provision for the irradiation of the sample with Xrays or ultraviolet light and for measurement of the induced luminescence during any part of the experiment. Upon termination of the irradiation the measurement of the luminescence can be continued at any desired temperature, and rapidly decaying phosphorescence can be detected. In all these experiments the sample remains undisturbed, and the problems associated with the heterogeneity of the sample are thus reduced. The apparatus has been used successfully in the study of electron trapping in zircon, sphene, and quartz.

GEOCHEMICAL PROCESSES AND SULFUR-ISOTOPE FRACTIONATION

Wayne U. Ault
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New meteoritic troilite sulfur^{32}/sulfur^{34} ratios for siderites from Odessa and Richlands, Texas, and from Xiquipilco and Toluca, Mexico, are 22.18, 22.23, 22.20, 22.22, respectively, relative to the accepted value for Canyon Diablo as 22.21. The National Bureau of Standards Isotope Ref. sample No. 180 analyzes 22.18. Precision is within ±0.02 per cent.

Isotopic composition of the sulfate ion in the present ocean reservoir is remarkably constant. Depth profiles taken from five large basins in the North Atlantic and South Atlantic and North Pacific oceans and from the Gulf of Mexico showed an average S^{32}/S^{34} ratio of 21.77 ±.01 with a range of only 0.15 per cent of the ratio. This is significantly smaller than the 0.5 per cent range previously reported. Sea water from Laguna Madre, Texas, analyzed 21.77. Gypsum currently deposited in the lagoon analyzed 21.80. Old sulfate deposits indicate a complicated history. Gypsum and an-

hydrite from extensive Paleozoic to Tertiary deposits gave values (21.55 to 21.99) which do not correlate with age. Silurian anhydrite beds in Michigan and Montana analyzed 21.67 and 21.65. Cretaceous anhydrite from Florida showed a 0.6 per cent trend over a 9000-foot depth profile.

Selenite forming on pyrite-bearing boulders from the Highlands region of Franklin, New Jersey, and Lake Welch, New York, indicated a nearly quantitative oxidation of the sulfide to sulfate during weathering. The sulfur ratios of a 2-inch galena crystal from Indian Creek, Missouri, showed a continuous increase (0.6%) from the vug contacts to the extremities of growth. This variation probably represents a change in isotopic composition of the solution during the crystal growth.

CRYSTAL-CHEMICAL STUDIES OF FIBROUS CALCIUM-SODIUM VANADATES

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The following minerals belonging to this group have been described previously: hewettite, $CaO \cdot 3V_2O_5 \cdot 3H_2O$; metahewettite, $CaO \cdot 3V_2O_5 \cdot 9H_2O$; and the sodium analogue of hewettite, $Na_2O \cdot 3V_2O_5 \cdot 3H_2O$ (A. D. Weeks, 1954). In addition, the probable existence of a calcium-sodium vanadate from the Colorado Plateau has been established: $(Ca,Na_2)O \cdot 3V_2O_5 \cdot 2H_2O$ (W. H. Barnes, 1955).

Contrary to the natural hewettites and metahewettites (with the exception of the sodium analogue) this mixed calcium-sodium variety appears to be water insensitive. All evidences indicate the strong structural similarity to vanadium pentoxide, V_2O_5. Double chains of five-fold vanadium-oxygen polyhedra extend along the *a* axis, while cations and water molecules occupy tunnel-like interstices between them. While the *a*- and *b* parameters of the compounds belonging to this group are all nearly identical, the *c* parameters vary with the degree of hydration, thus indicating a remarkable "elasticity" of this particular lattice type in the *c* direction. The structures show slight differences when compared with each other, but the general principle (double chains of five-fold vanadium-oxygen polyhedra) is common to all the natural and synthetic polyvanadates of this group investigated so far, including artificially dehydrated and fused material. This increases the number of vanadium compounds in which vanadium is known to occur in five-fold co-ordination.

RHACHITOMOUS VERTEBRAE IN THE LOXOMMID AMPHIBIAN *MEGALOCEPHALUS*

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Whether Carboniferous amphibians of the superfamily Loxommoidea should be assigned to the anthracosaur-reptile lineage or the temnospondyl lineage of the Labyrinthodontia has long been debated. Lack of contact between parietal and tabular bones of the skull roof has favored assignment to the Temnospondyli, but the conclusive evidence of vetrebral structure has hitherto been lacking. A vertebral column with typical rhachitomous intercentra, associated with a skull of the loxommid *Megalocephalus* from Linton, Ohio, now firmly establishes the temnospondyl interpretation advanced by Romer. *Megalocephalus*, well represented in the Westphalian coal measures of England and Scotland, is shown to occur also in the Gaskohle of Bohemia (Westphalian D) as "*Loxomma bohemicum*" of Steen, and in the mid-Pennsylvanian Upper Freeport coal of Linton, Ohio (Westphalian D), as *M.* [*Leptophractus*] *lineolatus* (Cope) (= *Macrerpeton huxleyi* of Romer, in part).

TRACE-ELEMENT DISTRIBUTION IN SHALES NEAR THE HANOVER, NEW MEXICO, MINING AREA

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Cu, Zn, and Fe were determined in 80 samples of the lower Paleozoic shales, limestones, and dolomites which underlie the major Pb-Zn-Cu ore-producing zone in the "contact" metasomatic deposits about the granodioritic intrusion near Hanover, New Mexico.

In unaltered sediments several miles from the intrusion: (1) The Zn and Cu content varies regularly from 70 and 50 ppm in a relatively lime-free shale to 15 and 5 ppm, respectively, in a limestone. (2) In detail, each metal varies independently; Zn is a uniformly distributed trace element, while Cu occurs in discrete mineral grains. (3) Metal content is approximately constant along strike but may change abruptly between zones. (4) Both ground-water penetration and local hydrothermal alteration may either increase or decrease Cu or Zn content by a factor of at least 3; consequently, variation between adjacent samples usually exceeds analytical error (standard deviation $\leqq$ 10% for Cu and Zn, about 25% for Fe).

Near the intrusion, porcelainite or marble (excluding skarn) carries about the same total metal content as the original sediments.

Change in the metal content of these sediments on metamorphism is insufficient (by two orders of magnitude) to contribute appreciably to the metal content of the ore deposits. The exposed Precambrian greenstone contains more than 0.05 per cent Zn, 0.1 per cent Cu, and 15 per cent Fe and may have contributed to the metal content of the deposits.

PRELIMINARY REPORT ON THE SYSTEM FeS-ZnS-S AND IMPLICATIONS REGARDING THE USE OF THE SPHALERITE GEOTHERMOMETER

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The simple binary system FeS-ZnS adequately represents the system pyrrhotite-sphalerite observed in ore deposits; however, attempts to employ the FeS-ZnS system as a geothermometer for pyrite-sphalerite assemblages where pyrrhotite is absent are open to criticism.

The preliminary work in this study of the ternary system FeS-ZnS-S, as well as the original work by Kullerud, has shown that the activity of FeS in pyrrhotite of all compositions is fairly close to unity, and thus the iron content of sphalerite in equilibrium with pyrrhotite (even in the presence of pyrite) is close to that predicted by the simple binary system FeS-ZnS. Unfortunately, the simple picture does not hold when the amount of sulfur increases to the point where the iron sulfide is pyrite instead of pyrrhotite. At constant temperature, the iron content of sphalerite in equilibrium with pyrite is a strong inverse function of the sulfur vapor pressure. Temperatures estimated using the FeS-ZnS data for sphalerite in equilibrium with pyrite can be as much as 300°C. too low, but, in any event, the FeS-ZnS system does give a minimum temperature of formation for any sphalerite. To apply the sphalerite geothermometer to pyrite-sphalerite assemblages we must evaluate the partial pressure of sulfur vapor. This may be done, or at least limits may be placed on possible variations in sulfur pressure, through the use of various minerals commonly associated with sphalerite and pyrite (bismuthinite-native bismuth, argentite-native silver, the copper sulfides, and others), which provide possible sulfur pressure barometers.

COPPER VERMICULITES FROM NORTHERN RHODESIA

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Vermiculite has been identified as the chief copper-bearing mineral in samples of micaceous material from the copper belt of Northern Rhodesia. These samples contain from 2 to 7 per cent copper, which is carried in the exchange position of the vermiculite. Copper vermiculite was synthesized from magnesium vermiculite and from a pure biotite by simple base-exchange procedures. The resultant materials give X-ray diffraction patterns with intensities for 7A, 4.67A, 3.5A, greater than those of a magnesium vermiculite indicating that copper had entered the exchange position of the vermiculite lattice. The natural samples give X-ray diffraction patterns having a similar distribution of intensities. In some of the natural samples this intensity distribution must be attributed to the presence of chlorite, but in others it is due to copper in the exchange position. Vermiculite has been distinguished from chlorite on the basis of differential thermal analysis, direct-weight measurements of H_2O loss between 25°C. and 260°C., continuous X-ray diffraction during heating on the thermal-increment diffractometer, and by exchanging large univalent ions from small bivalent ions in the exchange position.

Copper appears to be firmly fixed in the lattice, and no simple base-exchange procedure was found for its removal from either the synthetic or the natural material.

ECOLOGY OF RECENT PLANKTONIC FORAMINIFERA IN OCEANIC WATERS OF THE WESTERN NORTH ATLANTIC

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Recent planktonic foraminiferal assemblages from quantitative plankton samples in the western North Atlantic record broad ecological changes in the euphotic zone. The horizontal distribution of each species is expressed as (1) number of specimens per 1000 m^3 of water, and (2) percentage of the total planktonic foraminiferal population. The former, a measure of the standing crop, indicates that 14 out of 18 species are most abundant in the Gulf Stream system where strong temperature and salinity gradients exist; they decrease significantly north and south of this current system. The second method of representation segregates species in more definite temperature zones than the first method, because the percentage of "warm-water" species increases southward to the Sargasso Sea, and the percentage of "cold-water" species increases northward to the slope waters.

Studies of vertical distribution in Bermuda waters indicate that the planktonic Foraminifera are mostly restricted to the upper 200 meters of water—approximately to the euphotic zone.

A strong seasonal fluctuation in the abundance of 11 out of 15 species is observed from a comparison of tows taken in Bermuda waters in August 1955 and January 1957. "Summer" species are *Globigerinoides rubra* (pink tests), *G. conglobata*, *G. sacculifera*, *Globorotalia punctulata*, *Orbulina universa*, and *Hastigerina pelagica*. "Winter" species are *Globorotalia truncatulinoides*, *G. hirsuta*, *Globigerina inflata*, *G. bulloides*, and *G. eggeri*. Four species do not show any significant seasonal variation.

RELATIONSHIP OF GEOLOGY TO TERRAIN

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The concept of terrain as the sum of all features found at or near the earth's surface provides a basis for integrating knowledge isolated in different scientific fields. This concept recognizes also human influences on natural features, disregarded generally by some earth sciences, particularly

geology. The inadequacy of single sciences to answer certain practical problems completely has dictated the need for this concept. For instance, engineering problems can call for consideration of geologic, soil, vegetation, drainage, topographic, and climatic conditions. The relative importance of any factor depends on its significance in the composition of the segment or type of terrain under study and in the proposed application. Instead of separate investigations of the different factors, terrain evaluation strives for combined research by close collaboration among the sciences concerned. So far, the study of terrain has been pursued mainly for military applications. Some problems are uniquely military, but most are found also in civilian life. Thus, interpretation of the effect of terrain on engineering operations need not be limited to military construction. The practical investigations indicate that basic research on the relationships among elements of terrain is needed for both purely scientific and applied purposes. Terrain research has, furthermore, created the need for new types of maps to show basic terrain data and interpretations. In the development of terrain research and the fostering of combined investigations, geology has assumed the leadership in the United States.

GUBIK FORMATION OF QUATERNARY AGE IN NORTHERN ALASKA

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The unconsolidated Gubik formation of Quaternary age unconformably mantles rocks of Cretaceous or Tertiary age throughout the Arctic Coastal Plain Province of northern Alaska. The Gubik largely comprises lenses and admixtures of silt and fine-grained sand in which quartz and chert predominate. Other minerals total less than 10 per cent. The sediments are dominantly marine, but fluvial, lacustrine, eolian, and frost processes are involved.

Three main lithologic units are distinguished:

Oldest—commonly poorly sorted clay to cobbles; dark; marine mostly, but probably glacial in part; deposited unconformably on indurated rocks west of the Colville River; maximum thickness 20 feet; poorly exposed

Intermediate—clean, light-colored, well-sorted marine sand; generally unconformable on oldest unit; locally unconformable on bedrock and conglomeratic at the base; forms dunes; commonly grades upward into loess in the southern and southeastern area; maximum thickness 200 feet.

Youngest—poor to well-sorted mixtures of clay, silt, sand, and gravel; variable color; in part contemporaneous with intermediate unit, in part younger; ice locally constitutes more than half; organic matter abundant in upper part; rarely deposited on indurated rocks; generally marine, but fluvial and lacustrine locally; few tens of feet thick.

The Gubik represents a shallow near-shore shelf environment with frequent migrations of the strand line in a relatively short time. Parts of the uppermost sediments are less than 2000 years old; various evidence suggests that the two younger units are no older than late Pleistocene (possibly Sangamon) and the oldest possibly middle Pleistocene.

REBOUND PROBLEM IN THE PIERRE SHALE AT OAHE DAM, PIERRE, SOUTH DAKOTA—PART III

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The outlet works of the Oahe Dam pass water through the dam for regulation of the pool level and the river levels downstream. Under normal head of approximately 190 feet, the energy of the released water must be dissipated before the water returns to the river. The stilling basin performs this vital function. Because of the necessity for frequent operation at high velocities of flow and the difficulties of repairs, it was felt that there should be every reasonable assurance that the structures would operate as designed even under the adverse foundation conditions.

At the time the differential movements occurred, the initial designs had been completed, and the contract for construction had been signed. The foundation movements posed an immediate question as to the adequacy of the design of the structures which were to be placed thereon and were a threat to the completion of the project on schedule. Several variations of redesign were considered on a more or less crash basis in order that the construction schedule would not be unduly affected. Simultaneously, prototype data were being collected in the field to predict future foundation movements, the effect the movements might have on the superimposed structures, and corrective measures that could be taken to reduce movement and damage. The adopted redesign included increased articulation to prevent insufferable damage in case of continued movement and added many anchor bars under the structures to retard the expansion of the foundation.

Observations, after a limited time, indicated satisfactory performance of the redesign.

GRAVITY ANOMALIES IN SOUTHERN IDAHO AND SOUTHWESTERN MONTANA

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Bouguer gravity anomalies for 800 locations show a prominent maximum associated with the Snake River Downwarp. The maximum extends from northeast of St. Anthony, Idaho, to west of Nampa, Idaho, and for the most part is parallel to and north of the present course of the Snake River. The maximum (least negative) value is −70 mgals., 10 miles southwest of Mountain Home, Idaho. On the maximum trend east of this, values are progressively more negative. A gravity gradient of about 5 mgals./mile on the north edge of the Snake River maximum from Boise through Mountain Home and King Hill, Idaho, suggests that the north edge of the downwarp in this area may be fault-controlled.

A broad minimum with a most negative value of −236 mgals. is centered on the southeastern edge of the Idaho batholith.

Although no isostatic anomalies have been calculated, local adjustment apparently has been approached in these large crustal units, in contrast to the lack of local adjustment in the smaller basin and range-type features.

Work is continuing to extend coverage west into eastern Oregon and Washington and north to Canada.

POSITION OF NORTH ATLANTIC SILURIAN-DEVONIAN BOUNDARY

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Restudy of the position of the Silurian-Devonian boundary in the regions bordering the North Atlantic suggests that it can be easily recognized in the brachiopod-rich facies by the incoming of a number of genera previously unknown in the region including *Mutationella*, *Podolella*, aff. *Nanothyris*, *Platyorthis*, *Fascicostella*, *Proschizophoria*, *Scenidium*. E. I. White's studies of pteraspid fishes strongly support the view that the lower Gedinnian of Belgium is a correlative of the Anglo-Welsh Downtonian. If the Ludlow Bone Bed is accepted as the base of the Devonian, as proposed by White, the Manlius, Coeymans, and upper Keyser limestones of the Appalachians will be assigned to Lower Devonian and the Cobleskill Limestone to Upper Silurian. If the stratigraphically youngest occurrence of monograptids is used to define the Silurian-Devonian boundary then the recent discovery in Czechoslovakia of monograptids in F-f_1 (couches de Lochkov) would result in the assignment of the Downtonian and possibly part of the Dittonian to the Silurian. In the Appalachians F-f_1 is probably represented by the upper part of the Helderberg Group.

SYSTEM $MgSiO_3$-$CaMgSi_2O_6$

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A phase-equilibrium study of the pyroxene quadrilateral $MgSiO_3$-$CaMgSi_2O_6$-$CaFeSi_2O_6$-$FeSiO_3$ has been undertaken. It has proved necessary to re-examine the phase relations along the sidelines of the quadrilateral, and preliminary results have been obtained for the join $MgSiO_3$-$CaMgSi_2O_6$. Bowen's study of the melting relations along this join has been checked in detail and confirmed. The writers have determined the position of the solvus between $MgSiO_3$ and $CaMgSi_2O_6$ utilizing X-ray methods for the determination of compositions of phases. Runs on the solvus have been made dry above 1100°C., and hydrothermally at 500 bars (H_2O) in the interval 800°–1150°C. The work confirms the results of Atlas in the approximate position of the solvus, but the writers have found that the solvus intersects the solidus over a composition interval of about 15 weight per cent. The points of intersection are $En_{55}Di_{45}$ and $En_{40}Di_{60}$ at a temperature of 1390°. Homogeneous pyroxenes cannot exist stably in the composition interval between En_{40} and En_{55}.

The writers have prepared well-crystallized orthoenstatite and protoenstatite by hydrothermal methods. However, we are not yet sure of the stable high-temperature form of $MgSiO_3$. This problem is being investigated with a diffractometer heating stage.

COAL RESOURCES STUDIES IN OHIO

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At present Ohio's original coal reserves are estimated at 43,855,450,000 short tons. Coal production for the 1800–1955 period amounts to nearly 1.9 billion tons, which represents approximately 3.8 billion tons of coal mined and lost in mining. Remaining reserves are estimated at 40 billion tons, and recoverable reserves at 20 billion tons.

Reserves occur in the Pennsylvanian and Permian systems, and the Allegheny series contains the greatest portion of the estimated reserves to the extent of 62.7 per cent. Monongahela series contribute 25.5 per cent of the estimated reserves, Pottsville series 7.7 per cent, and the Conemaugh series 3.0 per cent. The Permian system contains 1.1 per cent of the estimated reserves.

Twenty-three coal beds are considered minable at one place or another; 11 of these were analyzed in detail on O'Neill area maps at a scale of 1:62,500. The estimates of the other coal beds were treated by either accepting previous estimates or making adjustments of such estimates from more recently acquired data.

EVIDENCE FOR A MAJOR CLIMATIC CHANGE CLOSE TO 11,000 YEARS B.P.

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Recent studies at the Lamont Geological Observatory have led to the idea that a major change in climate occurred rather abruptly close to 11,000 years ago. The evidence for this change has been found in a number of widely separated climate-sensitive systems. The events in the various systems are correlated on the basis of C^{14} measurements. Evidence from the Great Basin region suggests that the pluvial lakes found in this area underwent a rapid decrease in level at this time. Studies carried out on ocean cores taken from the Atlantic Ocean and adjacent seas indicate that the change in surface-water temperature found on the basis of faunal evidence by Ericson was nearly simultaneous throughout this system and occurred close to 11,000 years ago. The sedimentation rate of both carbonate and lutite in the equatorial Atlantic appears to have been significantly greater before than

after this date, suggesting a change in the surface current systems. The turbidity currents which deposited a layer of clay more than 50 feet thick over the abyssal plain of the Gulf of Mexico (Ewing *et al.*, 1957) ceased abruptly close to this time suggesting a change in the operation of the Mississippi River system. There is a suggestion of a rapid retreat of the mid-continent glaciers from their Valders maximum. The combined evidence indicates that this event may well mark a change from glacial to interglacial conditions.

CRYSTAL STRUCTURE OF CALLAGHANITE $Cu_3Mg_3(CO_3)_4(OH)_{24}\cdot 8H_2O$

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The crystal structure of callaghanite, $Cu_3Mg_3(CO_3)_4(OH)_{24}\cdot 8H_2O$, has been determined from X-ray precession and Weissenberg photographs of single crystals of the naturally occurring material. The crystal system in monoclinic, the space group is C2/c, and the unit-cell dimensions are a = 10.06Å, b = 11.80Å, c = 8.24Å, and $\beta = 107°18'$. There are four molecules per unit cell.

Two-dimensional Fourier syntheses were computed to obtain (001) and (100) electron-density projections. These projections were used to determine the final parameters of the atoms.

The carbonate group is bonded only to magnesium atoms, and one oxygen of this group is not bonded to either magnesium or copper but is hydrogen-bonded to the water molecules. The Mg-(OH) bonds average 2.06Å; the Cu-(OH) bonds, 2.01Å; the Cu-H_2O bonds, 2.77Å; and the Mg-H_2O bond, 2.24Å. The C-O bonds are 1.41Å, 1.41Å, and 1.29Å. The copper atom has four (OH) groups as nearest neighbors at a distance of 2.00Å and a water molecule as next nearest neighbor at a distance of 2.23Å forming a distorted pyramid around it.

LABORATORY STUDY OF KNICKPOINT BEHAVIOR IN NONCOHESIVE MATERIAL

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Knickpoints were molded in the beds of model channels formed in well-sorted, noncohesive sands 0.67 and 2.0 mm in diameter, by oversteepening a reach 1 foot long, providing a fall of 0.1 foot. The total length of the gently sloping remaining channel was 50 feet. Progressive changes in knickpoint position and in the initially oversteepened slope were measured while discharge, overall slope, and particle size were varied independently.

In each run, the water-surface slope and bed slope below the knickpoint decreased with time. At the lower end of the oversteepened reach, sediment eroded from the reach above constructed a dune which advanced downstream, causing the channel to widen and steepen initially. Following the passage of the dune, the slope again flattened. While the knickpoint advanced upstream, the channel above the knickpoint first steepened and narrowed after which the slope decreased.

For identical initial overall slope, discharge, and width, the rate of decrease of slope below the knickpoint was faster in the channel of finer sand.

The rate of change of slope below the knickpoint depends on the rate of sediment transport. If the rate of transport is great, the slope below the knickpoint is reduced quickly, which implies that the higher the initial slope, the more rapid the rate of decrease of slope. These results are comparable to changes observed following meander cutoffs in rivers and confirm the observation that headward migration of knickpoints accompanied by undiminished slopes cannot occur in the absence of resistant bed material.

MAGMATIC RELATIONSHIPS IN NORTHERN VERMONT AND SOUTHERN QUEBEC

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Igneous rocks in northern Vermont and adjacent southern Quebec include, in chronological order of peak development: (1) mafic volcanic rocks, (2) felsic volcanic rocks, (3) concordant mafic hypabyssal and plutonic rocks, (4) concordant plutonic ultramafic rocks—Ordovician, (5) concordant intermediate to felsic plutonic rocks—Devonian, (6) discordant felsic to mafic plutonic rocks, and (7) discordant felsic to mafic dike rocks—Mississippian. Two kindreds are probably represented: a calc-alkalic kindred that includes mafic and felsic volcanic rocks, concordant mafic hypabyssal rocks, and intermediate to felsic plutons; and an alkalic kindred that includes all the discordant plutons and dike rocks. The ultramafic rocks are possibly an early differentiate in the calc-alkalic kindred. The calc-alkalic rocks are pretectonic to syntectonic, and the alkalic rocks are post-tectonic. The ultramafic rocks include pretectonic magmatic intrusive rocks and syntectonic intrusive rocks that were emplaced in the solid state.

Volcanic and mafic hypabyssal rocks of the calc-alkalic kindred are interbedded with and intrude only Cambrian and Ordovician strata in the Green Mountain-Sutton Mountain anticlinorium of Vermont and Quebec, but occur with strata as young as Devonian in the Boundary Mountain anticlinorium of easternmost Vermont, northern New Hampshire, and adjacent Quebec. Ultramafic rocks occur chiefly at stratigraphic levels below the Middle Ordovician; thus they are abundant in the Green Mountain-Sutton Mountain anticlinorium and are scarce in the Boundary Mountain anticlinorium, where strata of pre-Middle Ordovician age are probably not exposed. Mafic dike rocks of the alkalic kindred occur throughout the region.

MACERAL GROUPS CHARACTERIZING THE ELKHORN SEAM AT EVANSTON, KENTUCKY

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A column sample of Elkhorn Seam coal collected in the vicinity of Evanston, Kentucky, was analyzed megascopically and microscopically. A polished master column was utilized for the former type of analysis. The seam was divided into intervals on the basis of differences observed megascopically. Representative thin sections were then prepared for these intervals and analyzed in terms of their maceral groups—that is, vitrinoids, fusinoids, micrinoids, resinoids, and exinoids. Mineral matter was also included as an entity. Examination of the data thus derived revealed that the Elkhorn seam, as characterized by this sample, is a bright coal, high in the vitrinoids. A conspicuous durain band high in micrinoids and exinoids occurs in the upper third of the seam. A discontinuous zone of carbonate concretions in the lower third of the seam revealed interesting maceral and mineral-matter associations.

TEACHING AND RESEARCH: IMMISCIBLE COMPONENTS OR ISOMORPHOUS SERIES?

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Two answers are extant: (1) teaching and research do not blend, and any attempt to achieve a blend results in a mixed-up character who inevitably will impart his frustrations to his students; (2) teaching and research theoretically and practically do blend in all proportions, and the only problem lies in what proportions are best. The circumstance that in teaching-and-research, just as with min-

eral isomorphous series, "pure end members" rarely occur, is only one of several features that support the second answer. More important is the fact that within any random group of sufficient size, one or more individuals can be found whose proclivities may be designated as $Te_{95}Re_5$ (Te = teaching; Re = research), while others will be $Te_{90}Re_{10}$, and so on—to some who will exemplify Te_5Re_{95}. What a college needs in a staff appointee will depend on the objectives of the school and the level of training. Thus for teaching freshmen a basic discipline such as mathematics, perhaps a $Te_{90}Re_{10}$ is best, whereas for guiding Ph.D. programs in geology, a $Te_{10}Re_{90}$ will be preferable. Studies might well be undertaken to determine the degree (if any) to which, by varying P-T-X conditions (the total environment), it may be possible to alter the natural Te–Re ratio within an individual. Development of a successful procedure for accomplishing this would provide flexibility for faculty groups facing changing demands in education.

CHARACTER OF THE PRE-WISCONSIN VALLEY OF THE UPPER OHIO RIVER

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Precisely controlled test-hole borings to bedrock along the upper Ohio River indicate that the initial 110 miles of the pre-Wisconsin bedrock valley is steeper in longitudinal slope than the present channel, which is cut in valley fill of Wisconsin age. From mile 113 (below Pittsburgh) to mile 316 at Kenova, West Virginia, the slopes of the bedrock channel and the present channel coincide closely at an average gradient of 0.5 foot per mile. From Pittsburgh to Kenova the bedrock channel slope, expressed by a regression equation, is: $\log Y_e = 2.8090 - .0004\,X$.

From Pittsburgh to mile 165 the mean valley-floor width is 0.73 mile with a standard deviation of only 0.15 mile. At mile 165 the valley widens markedly, and for the next 91 miles the mean width is 0.96 mile, with a standard deviation of 0.29 mile. Between mile 165 and mile 185 the Muskingum and Little Kanawha rivers increase the average annual discharge of the Ohio River from 41,300 cfs to about 52,800 cfs. From mile 256 to Kenova, at mile 316, the mean width of the valley is 1.21 miles with a standard deviation of 0.29 mile. At mile 265 the Kanawha River adds about 5000 cfs in average annual discharge. A genetic relationship appears to exist between the discharge of the river and its power to erode laterally.

Test borings at U. S. Corps of Engineers lock and dam sites show the bedrock valley to have the transverse form of a flattened U.

MICRO-MECHANISMS OF SEDIMENTATION IN EPICONTINENTAL ENVIRONMENT

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Difficulties will always arise if we presume to compare conventional stratigraphic columns (macrolithology) with corresponding geophysical logs (responding to microvariations), because the causative phenomena are of two widely different orders of magnitude.

We should study closely spaced thin sections, compute data on frequency and maximum apparent grain size (clasticity index) of the principal microscopic components (detrital and authigenic minerals, benthonic and pelagic microfaunas, physico-chemical properties of the matrix), and plot these as a set of curves alongside the stratigraphic column, for comparison with the geophysical profile and the zonation of the index fossils.

Several mechanisms of the sedimentation have been outlined in numerous Paleozoic and Mesozoic sections of Europe through the investigation of the following problems:

(1) Behavior of the clasticity and the frequency of detrital minerals

(2) Relations between detrital minerals and authigenic components as glauconite, silica, and feldspars
(3) Behavior of iron compounds versus detrital and authigenic minerals
(4) Behavior of microfaunas versus mineral components
(5) Reciprocal relations between benthonic and pelagic microfaunas

It is suggested that microscopic investigation should become common practice because numerous processes of sedimentation of fundamental importance for the reconstruction of environments, since they are of small scale, are commonly overlooked.

AUSTRALIAN AND NEW ZEALAND DEVONIAN AND SILURIAN CARPOIDS

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Carpoid echinoderms are described from Australia and New Zealand Devonian and Silurian for the first time, and world comparisons are drawn. *Rutroclypeus* Withers from the Victoria Lower Devonian is a dendrocystitid instead of a limulid as originally supposed. A new species of that genus is described, and in connection with a revision of the world dendrocystitids one new genus and two new families are described in the order Soluta.

Two new mitrate (placocystoid) carpoids (two new genera, and species) are described from the Victorian Silurian of Australia and the Reefton Devonian of New Zealand. Considerable attention is given to carpoid morphology and differentia.

In view of the recentness of carpoid discovery in the Southern Hemisphere, and their known presence now in most of the "Gondwana" fragments (Brazil, Union of South Africa, Australia, and New Zealand), it is of interest to note that the australasian forms appear to be unrelated to the South Atlantic forms of Brazil and Africa, and instead show European and North American affinities in keeping with the general Devonian and Silurian biotae of that realm.

STRATIGRAPHIC RELATIONS IN FRENCHMAN'S BAY REGION, MAINE

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Shaler considered the Bar Harbor series of well-bedded, fine-grained graywacke and siltstone as distinctly younger than the Cranberry Island series of volcanic breccia, tuff, and flows. Chadwick considered the Bar Harbor series a northern detrital facies, which interfingered with the Cranberry Island series to the south. Neither interpretation, however, was well supported by field evidence.

The volcanic series has a northeasterly trend and is correlated with middle or upper Silurian volcanic rocks of the Eastport area. It was folded and weakly metamorphosed probably during late Silurian or early Devonian. The Bar Harbor series is unmetamorphosed but is broadly warped into a structural basin in the northern half of Frenchman's Bay.

Along the northeastern and eastern margin of this basin a conglomeratic member has recently been found. This member attains a thickness of about 1500 feet and consists of coarse- to medium-grained graywacke interbedded with conglomerate near the base. The conglomerate layer is up to 150 feet thick and is composed predominantly of well-rounded pebbles and cobbles of volcanic rock up to 2 feet across. Above the graywacke member and interbedded with it are beds of the typical Bar Harbor series.

At one locality a well-exposed patch of the conglomerate rests unconformably on the foliated and lineated volcanic rocks, and pebbles of the volcanics are enclosed in the conglomerate.

These relations not only confirm Shaler's belief but suggest that the Bar Harbor series is probably of Devonian age.

ISOTOPIC COMPOSITION OF LEAD IN MANGANESE NODULES

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The isotopic composition of lead in manganese nodules found on the floors of the Pacific and the Atlantic oceans was determined.

	No. of Specimens	Pb^{206}/Pb^{204}	Pb^{206}/Pb^{207}	Pb^{206}/Pb^{208}
Pacific Ocean	16	18.69	1.197	0.4814
Atlantic Ocean	10	18.96	1.213	0.4853

The data on the oceanic lead were compared with the analyses of a series of lead samples taken from a lead nitrate reference solution. The isotopic compositions of the oceanic lead were spread over a slightly wider range than those of the reference solution, but no definite contrast could be found. When samples from the Pacific were compared with those from the Atlantic there was a distinctive difference in the isotopic composition of lead. The isotopic composition range of the Pacific lead did not overlap that of the Atlantic. The difference between the averages of the Pacific and of the Atlantic samples was much greater than the assigned experimental error.

The slight difference in isotopic compositions of lead from various localities within an ocean and the distinctive difference between the Pacific and the Atlantic leads may be caused by the introduction of various leads to the oceans from different types of rocks. Is it postulated that the Atlantic lead was derived from rocks which contained high proportions of aged granites and that in the Pacific from rocks containing high proportions of aged basalts.

NATURE OF THE POLYIONS IN SOME BORATE MINERALS

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Crystal-structure investigations of the series $2CaO \cdot 3B_2O_3 \cdot xH_2O$ have shown that meyerhofferite ($x = 7$) and the synthetic ($x = 9$) contain the polyion ring $[B_3O_3(OH)_3]^{-3}$, and that in colemanite these ions polymerize to form infinite chains of composition $[B_3O_4(OH)_3]_n^{-2n}$. Since inyoite ($x = 13$) alters readily to meyerhofferite, it seems likely that inyoite (being worked out at present) contains these same polyions.

The polyion ring, consisting of two linked $BO_2(OH)_2$ tetrahedra and a $BO_2(OH)$ triangle, is evidently a particularly stable configuration. It is stereochemically possible to add only one $BO_2(OH)$ triangle to this ring. This resulting polyion, $[B_4O_5(OH)_4]^{-2}$, has in fact recently been found in borax by N. Morimoto. Considering the physical properties of the series $Na_2B_4O_7 \cdot yH_2O$, it seems likely that tincalconite ($y = 5$) and kernite ($y = 4$), respectively, bear the same structural relationship to borax ($y = 10$) as meyerhofferite and colemanite do to inyoite.

VARIATION ASPECTS OF SOME BATHONIAN (MIDDLE JURASSIC) LAGENIDAE

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The Lagenidae in the English Bathonian exhibit patterns of variation similar to those previously described from the Lias and similarly require a flexible application of morphological criteria in delimiting species and genera.

Highly uncoiled forms identical with figured specimens of *Lenticulina matutina* (d'Orbigny) occur and intergrade with tightly coiled representatives of *Lenticulina munsteri* (Roemer), suggesting synonomy of the two species. Variants of *Dentalina mucronata* Neugeboren include broad, slightly

sigmoid forms indistinguishable from slender end members of *Vaginulina legumen* (Linnaeus), and it is only by differences in distributional patterns that the two species can be discriminated. In *Lenticulina tricarinella* (Reuss) there are gradations from the normal flat type to triangular *Saracenaria*-like forms, and in *Lenticulina turgida* (Schwager) occasional specimens have the last chamber overlapping on one side as in *Darbyella*. Variants of *Dentalina intorta* Terquem have the later chambers added in a plane 90° from the earlier ones, a plan of growth reminiscent of the family Polymorphinidae. Inverted V chambers occur in specimens of *Planularia beierana* (Gumbel), supporting previous observations from the Lias of this growth plan in species of normally coiled Lagenidae and suggesting that the genus *Falsopalmula* Bartenstein as defined is a morphological type consisting in part, at least, of variants of several species.

Many of the Jurassic Lagenidae show little regard for specific or generic boundaries if conceived in a strictly morphological sense, and due emphasis must be given to the gradational and distributional aspects of the specimens in the taxonomy of the group.

ORIGIN OF CENTRAL TEXAS VERMICULITE DEPOSITS*

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Vermiculite occurs at many localities in Precambrian rocks of the Llano uplift. Commercial development of the deposits has not yet been successful, although several hundred thousand tons of friable rock containing 25 per cent or more vermiculite has been disclosed by drilling and prospecting. All deposits with potential economic importance are associated with basic igneous rocks, and they can be subdivided into several types by origin.

The largest deposits occur as irregular bodies of biotite schist enclosed in Valley Spring gneiss. The suggested paragenesis of the vermiculite-bearing rock is (1) intrusion of sills and irregular masses of gabbro into the Valley Spring gneiss before the close of regional metamorphism, (2) conversion of gabbro to amphibolite by regional metamorphism, (3) partial conversion of amphibolite to biotite schist by alkali metasomatism accompanying intrusion of granite and pegmatites at the close of metamorphism, and (4) alteration of biotite to vermiculite by weathering in a zone not more than 15 to 30 feet deep.

In one deposit the vermiculite occurs in weathered, nonfoliated hornblendite which escaped dynamic metamorphism but was subjected to retrograde changes which replaced part of the hornblende with biotite.

Veins of vermiculite and chlorite also occur in serpentine and soapstone. The vermiculite in these is probably hydrothermal; 50 feet below the surface it is similar to that in the weathered upper part of the veins. Some veins are associated with pegmatites, and at one deposit vermiculite forms reaction borders on soapstone fragments engulfed in pegmatite.

ANISOCERAS, NON ANCYLOCERAS, FROM THE CRETACEOUS OF TEXAS

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Ancyloceras was established by d'Orbigny for a group of uncoiled but widely divergent lytoceratids. Through a series of refinements this genus is now restricted to trituberculate forms. *Ancyloceras* has been reported from the Lower Cretaceous of Europe, Japan, North America, and South America and except in North America has been considered to have an Upper Barremian to Lower Aptian range.

Böse described *Ancyloceras* in Upper Albian rocks of northern Mexico. Adkins described *Ancyloceras* from the Weno (Upper Albian) of northern Texas, and this Upper Albian range in North

* Publication authorized by Director, Texas Bureau of Economic Geology

America has been recognized in the literature for more than 30 years. There is evidence based on other ammonoid genera as to the Late Albian age of the Mexico and Texas beds so any justified extension of the range of *Ancyloceras* would be based on the validity of the Texas-Mexico identifications. Comparison of the Upper Albian forms with described species from the classic Barremian and Aptian localities shows that the Texas specimens have affinities with but differ from *Ancyloceras s.s.* and are but the final straight shaft of the early helical *Anisoceras*. *Anisoceras* has long been recognized as an Upper Albian genus.

The bituberculate nature of *Anisoceras* as compared with the trituberculate *Ancyloceras* is the basis of distinction and is especially important when only the final shaft of *Anisoceras* is preserved as in the Texas and Mexico specimens.

QUANTITATIVE GEOMORPHOLOGY OF SMALL DRAINAGE BASINS OF SOUTHERN INDIANA

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Morphometric analyses of six small areas in the unglaciated part of southern Indiana provided data for determination of influence of lithology, per cent of unconsumed upland (stage of cycle), and regional relief upon scale and form properties of third-order drainage basins measured in the field and from topographic maps and air photographs. Lithology was especially important in determining the scale of the topographic units as reflected in stream lengths, basin areas, perimeters, and drainage densities. Rock type also influences, but in lesser degree, some dimensionless form measures as steepness of valley-side slopes and stream gradients. Percentage of unconsumed upland is most clearly correlated with length of overland flow, and fully mature areas show steeper valley-side slopes when compared with younger or older geomorphic areas. Regional-relief effects on morphology were either not present or were masked by other controls.

When compared with other regions in the humid continental climate of eastern United States, the morphology of southern Indiana basins shows close conformity in some of the form elements as circularity, bifurcation ratio, drainage density, and stream-length ratios. Some dimensionless qualities, however, as maximum valley-side slopes, stream gradients, and hyposometric integrals show wide ranges.

The quantitative data seem to substantiate descriptive land-form interpretations by earlier geomorphologists but add to precise information as to the nature of the changes.

USE OF SPECIALLY MADE MAPS IN MORPHOMETRIC STUDIES

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Important discrepancies were found between measurements of morphology obtained by use of the relatively small-scale topographic map (U.S.G.S. 1:24,000, Nashville quadrangle, Indiana) and data obtained from specially surveyed, large-scale field maps (1:600). From such comparative studies it is obvious that in southern Indiana many drainage basins that appear as first- or second-order basins on the maps of 1:24,000 scale prove to be at least fourth order when mapped in the field. Order of many of these basins can be increased to third order by use of stereopairs to complete the drainage network. For instance the mean area of 10 third-order basins (1:24,000) is from 10 to 100 times as large as the area of 2 third-order basins specially mapped from the same area (1:600); stream lengths are 3 to 5 times larger; and drainage density is 20 to 60 per cent as large. It is strongly urged that

quantitative geomorphic studies take such factors into account and that special large-scale maps be used wherever possible.

AGE OF THE SWEDISH KOLM

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A Middle-Upper Cambrian black shale formation from the province of Vastergotland, Sweden, is an important horizon in geochronology. The formation contains massive podlike bodies rich in organic matter and about 0.5 per cent uranium. The occurrence of these uranium enrichments in a well-identified Cambrian horizon provides a unique opportunity to establish an absolute age for this horizon, thus correlating the paleontological time scale with an absolute time scale.

Isotopic age determinations using isotope-dilution techniques show less discordance than previously reported, but the spread in ages must be explained before an absolute age can be arrived at.

206/238	207/235	207/206
440 ± 15	485 ± 15	720 ± 20
410 ± 30	445 ± 30	700 ± 40
460 ± 10	485 ± 10	645 ± 20
410 ± 15	440 ± 15	685 ± 20

The close grouping of the 207/235 age is more suggestive of radon leakage than lead loss. Preliminary measurements of radon leakage show room-temperature radon loss to be of an order of magnitude less than that needed to explain the discordance. Measurements at elevated temperatures may help in the assignment of an absolute age to this formation.

CONVERSION OF AMPHIBOLITES TO CHARNOCKITIC ROCKS IN THE SANTA LUCIA MOUNTAINS, CALIFORNIA

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Pre-late Cretaceous metamorphic rocks (Sur Series) that form the core of the Santa Lucia Mountains southwest of Monterey are largely of amphibolite facies, but charnockitic rocks occur extensively at Cone Peak (Lat. 36° 03′ N., Long. 121° 29′ W.) and Grimes Point (Lat. 36° 12′ N., Long. 121° 44′ W.). The Cone Peak amphibolites consist of plagioclase and red-brown hastingsitic hornblende (locally with diopside or biotite), and they are interlayered with quartzites, sillimanite-garnet schists, forsteritic marbles, and calcite-diopside-meionite granulites. Persistent lineations indicate these rocks were dynamothermally metamorphosed before high-temperature metasomatism which converted parts of the amphibolites to heterogeneous, coarse-grained veins and nodes consisting of quartz, andesine (commonly antiperthitic), hypersthene (En_{50}), garnet ($Al_{62}Py_{18}Gr_{18}Sp_2$), augite, and titanium-rich ore. The main compositional change was a relative increase in SiO_2.

At Grimes Point, thick tabular masses of coarse-grained, gneissic dioritic and tonalitic charnockites have migmatitic borders with amphibolites and calc-silicate rocks. Quartz is abundant in the more leucocratic rocks, but all these rocks contain intermediate plagioclase (antiperthitic), hypersthene (En_{50}), and brownish-green hastingsite. Late-formed pegmatoid segregations of garnet, plagioclase, and quartz, or of hypersthene, biotite, plagioclase, and quartz are widespread.

At both localities, "granulite facies" mineral assemblages have formed under wet rather than dry conditions; in addition to high temperatures, it may have been the high Al_2O_3 content of the rocks, and perhaps their high Na_2O:K_2O ratios, that are responsible for these assemblages.

RESEARCH AND EFFECTIVE TEACHING IN THE GEOLOGICAL SCIENCES

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Some geology teachers spend practically all their time and professional energies being teachers; others are so engrossed in geological research that they are incapable of communicating with students at any level of training. Most teachers of geology would be classed between these extremes, and many possess a reasonably good balance between research activity and teaching. Although obviously valuable to the teacher of geology, research activity possesses only relative values. It is difficult to determine when a teacher does too much or too little research or whether the research is bad or mediocre or good.

Despite its equivocal nature, research activity is the soundest criterion for determining that a geologist is professionally alive. It indicates some degree of scientific motivation and competence. Research work provides a fountainhead of enthusiasm every teacher must have to be truly effective. Particularly on the graduate level of instruction, a teacher's reputation in geological research tends to draw outstanding students who in turn inspire the teacher to achieve maximum effectiveness.

More important than attainment of ideal balance between research and teaching activities within each staff member is the attainment of nearly ideal balance in the departmental teaching staff as a whole. Geology teachers need to resist administrative attempts to force all teachers to conform to any prescribed pattern of teaching and professional activities.

STRUCTURE OF OROCOPIA MOUNTAINS, SOUTHEASTERN CALIFORNIA

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The Orocopia Mountains border the Salton Sea northeast of the San Andreas fault in Riverside County, California. The range core, composed of albite-chlorite schist, is separated on the southwest from deformed late Cenozoic nonmarine strata by the Hidden Spring fault, a branch of the near-by San Andreas.

Northeast of the Orocopia schist a mile-wide wedge of gabbro, diorite, anorthosite, gneiss, and alaskite lies between a northeast-dipping fault, at places folded, and a high-angle major fault marked by great crushing. These rocks, deformed and intruded by volcanic rocks, resemble rocks in the western San Gabriel Mountains, about 150 miles to the northwest.

Northeast of the high-angle fault augen gneiss with migmatite on the southeast and granite on the north underlies unconformably about 4800 feet of newly discovered fossiliferous marine Eocene strata which probably correlate with Coast Range middle Eocene. These rocks consist of sandstone and shale with conspicuous coarse breccia beds and exotic boulders. Unconformably overlying this sequence is a 5000-foot thick variable series of undated nonmarine conglomerate, sandstone, shale, and tuff, with volcanic flows and intrusions. Lenses of granitic breccia characterize the northwest, and platy tuffaceous sandstone with gypsum-bearing interbeds characterizes the southeast.

Major faults separate the area into tectonic blocks of different geologic history and local correlation across the faults is not possible. Understanding of the significance of these faults and others in the vicinity, like the San Andreas, awaits regional study such as that now underway. Strike separations dominate over dip separations on minor faults associated with complex folds.

SILICA STRUCTURE STUDIES. VII: THE HIGH-PRESSURE REGION OF MODEL AND HALF-BREED DERIVATIVES

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Because of the conflicting results on the quartz-coesite inversion from four other laboratories and in view of the failure to achieve reversibility, runs of up to 2 weeks duration were made in the pressure range 10,000–35,000 atmospheres with SiO_2, $AlPO_4$, $GaPO_4$, BPO_4, BeF_2, GeO_2, B_2O_3. The p-t curve obtained for SiO_2 is the lowest so far published though agreeing, within experimental error, with that of MacDonald. Only one other coesite form has been found—for BeF_2. The p-t curve for the $BeF_{2quartz}$-$BeF_{2coesite}$ transition lies very close to that for the SiO_2 analogue passing through a point at 550°C. at 20,000 atm. New phases have been obtained at high pressures from $AlPO_4$ and B_2O_3. Infra-red absorption patterns of various polymorphs of SiO_2, GeO_2 (and B_2O_3) are used to demonstrate the absence of any co-ordination change in coesite.

The influence of GeO_2 in solid solution in SiO_2 is to raise the pressure required to form coesite: the solid solubility of GeO_2 in quartz-SiO_2 itself is decreased from 33 mol per cent at 500°C. at 500 atmospheres to about 5 per cent at 500°C. at 20,000 atmospheres.

ARGON IN MICA AND THE AGE OF THE BERYL MOUNTAIN PEGMATITE, NEW HAMPSHIRE

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A^{40} and K^{40} measurements of margarites (calcium mica) from Chester, Pennsylvania, and Ashland, North Carolina, and potassium micas associated with the Beryl Mountain, New Hampshire, pegmatite and associated country rocks are used to show the probable absence of appreciable primary argon (other than absorbed atmospheric argon) in these minerals.

The margarites contain only about 1 per cent of the radiogenic argon content of muscovite and biotite specimens of similar age, and most, if not all, of this argon can be accounted for by the potassium content of the margarites.

Although beryl crystals from the Beryl Mountain pegmatite have occluded a large excess of both helium and argon, there is no evidence for a similar excess in muscovite, biotite, perthite, or albite in this pegmatite. Within experimental error muscovite in large books associated with perthite and quartz, muscovite associated with albite and beryl, muscovite from a xenolith, and muscovite from graphic granite give the same age.

The age thus derived for the Beryl Mountain pegmatite is 323 ± 10 m.y. This age is in close agreement with Pb/α ages reported by Lyons for minerals from the Oliverian and New Hampshire magma series.

TEACHING AND RESEARCH IN THE SMALL DEPARTMENT OF GEOLOGY

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The role of research as a foundation for teaching is primarily the concern of the small department. This presentation is founded upon the assumption that research stimulates good teaching in two respects: (1) the scientific viewpoint of the teacher is broadened, and he can bring to the classroom information fresh from his experience; (2) the teacher is given the stimulus for extensive reading.

Examination of trends in research and teaching during the past 50 years indicates:

(1) The number of small departments has increased impressively, and most have changed from units of one man to several men. Former large departments have increased in size, but the ratio of publications from faculties of small schools compared to those of large schools has remained about the same.

(2) Research output from large departments has been based increasingly upon elaborate laboratory work.

(3) Equipment in small departments is the same as was available to large departments 50 years ago.

(4) Graduates entering teaching are attracted to large schools with expensive equipment, low teaching loads, and better salaries.

(5) The teacher in the small institution has less time for research.

To improve research possibilities in small schools, specialized courses in geology should be reduced, and courses in physical sciences added to improve the students' background and lighten the teaching load. There is need for re-examination of areas of igneous and metamorphic rocks in the field, development of stratigraphic concepts, and reinterpretation of published data. Grants-in-aid must be supplied with the same liberal attitude as currently for laboratory studies.

SELENIUM IN THE PHOSPHORIA FORMATION IN IDAHO, WYOMING, UTAH, AND MONTANA

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The Meade Peak phosphatic shale member of the Permian Phosphoria formation in Idaho, Wyoming, Utah, and Montana contains some of the most seleniferous sedimentary rocks known, and the most seleniferous of these are in southeastern Idaho and western Wyoming.

Selenium, although present in all rocks of the shale member, is in highest concentration in carbonaceous mudstone and in phosphate rock. Analyses show that the selenium content of the phosphate rock ranges from a few to 300 ppm; and of mudstone, from a few to more than 1500 ppm.

The selenium content of rocks of the shale member shows a crude positive correlation with the contents of sulfur and of carbonaceous materials. No consistent correlation was found between selenium and P_2O_5. The positive correlation between selenium and vanadium suggested by earlier workers is not consistent, but the highest content of selenium occurs in a carbonaceous mudstone zone that contains a few tenths to more than 1 per cent V_2O_5.

REGIONAL IMPLICATIONS FROM GEOLOGY OF BULL RUN QUADRANGLE, NORTHEASTERN NEVADA*

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The Bull Run quadrangle adjacent to Mountain City in northeast Nevada has the following tectonic history: (1) 25,000 feet of lower Cambrian to Devonian(?) basal sandstone, major carbonate and minor shale deposition; (2) post-Devonian(?) major east-west folding; (3) large-scale low-angle thrusting involving an allochthonous argillaceous and cherty western Paleozoic assemblage from the west or north; (4) probable Cretaceous intrusion of small diorite to granodiorite stocks; (5) Miocene(?) rhyolite volcanic rocks followed by or in part equivalent to lacustrine, fluvial, and pyroclastic late Miocene sediments in local yoked basins formed by incipient block faulting; (6) Pliocene rhyolite and andesite volcanic rocks with a local vent; (7) north- and northeast-trending

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normal block faults beginning in late Miocene and intermittently active until Recent, forming present mountain ranges.

Early Paleozoic and Cenozoic geology in the quadrangle is analogous to accepted regional geology in northeast Nevada, but local and regional evidence supports a proposed eastward bend of the Manhattan geanticline from its presently located northern end along the north border of Nevada into Utah and then possibly northward into south-central Idaho. Strong east-west folds, inferred to be Mississippian, accompanied or postdated by major overthrusting from the northwest, follow this proposed positive element. Orogeny along this middle to late Paleozoic trend may have intermittently continued into the Mesozoic, and Laramide intrusives were emplaced along the earlier east-west grain.

GEOCHEMICAL CRITERIA FOR DISTINGUISHING MARINE FROM FRESH-WATER SHALES

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Quantitative spectrochemical analyses are presented for a suite of 70 shale samples of Pennsylvanian age, collected from sites where the fossil content permits the samples to be classified as of marine, brackish, or fresh-water origin. The organic fraction was separated by froth flotation, and spectrochemical analyses were made on the organic ash as well as on the raw shale. Relative clay-mineral ratios were estimated from X-ray diffraction charts by measuring the peak areas of the first-order basal reflections.

Five elements—boron, gallium, rubidium, nickel, and chromium—are shown to be in appreciably different amounts in marine shales and fresh-water shales; boron, rubidium, and nickel are higher in the marine shales, and gallium and chromium are higher in the fresh-water shales. The most pronounced difference is in the abundance of boron. Elements selectively enriched in the ash of the organic fraction of shales are silver, cobalt, copper, nickel, lead, tin, vanadium, zinc, and molybdenum. Of these, nickel and vanadium appear to be the best indicators of a marine environment of deposition.

The illite: kaolinite ratio is statistically higher in marine and brackish-water shales than in fresh-water shales, but the trace-element assemblage is more consistently diagnostic of the depositional environment. Results are tabulated and presented in the form of diagrams. In the region studied it appears possible to distinguish marine shales from fresh-water shales by quantitative spectrochemical determination of boron, gallium, and rubidium.

PLANT MICROFOSSIL ASSEMBLAGES IN LOWER ALLEGHENY COAL BEDS OF NORTHEASTERN OHIO, WESTERN PENNSYLVANIA, AND NORTHERN WEST VIRGINIA

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In the Brookville coal-Lower Kittanning coal interval of the lower Allegheny strata in the Upper Ohio River Valley area there are at least six recognized coal zones of which the Brookville (No. 4), the Clarion (No. 4a), and the Lower Kittanning (No. 5) coal beds are moderately extensive and well developed.

Plant microfossil assemblages in the Lower Kittanning, Clarion, and Brookville coal samples taken from core tests, oil and gas well cuttings, and outcrops have been determined. Thirty-two spore types belonging to 15 generic groups have been recognized in this study.

Tabulated counts, bench profiles, and composite histograms demonstrate that there are distinguishing microfloral assemblages in each of the three coal beds investigated. The results of this study indicate that it is possible to distinguish the Lower Kittanning, Clarion, and Brookville coal

beds of this area by their plant microfossil assemblages and that the study of these plant microfossil assemblages is an aid in making more accurate stratigraphic correlations.

LAYERED GABBRO OF SEILAND, NORWAY

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The island of Seiland, off the coast of Northern Norway, is the northeastern extension of a large province of layered mafic rocks which probably formed during the Caledonian orogeny. Within the province rhythmic layering is absent or only locally developed. In some areas inclusions of metamorphosed sedimentary and volcanic rocks are interlayered with the mafic rocks.

On the south coast of Seiland, a layered gabbro, free of inclusions, rests on a base of garnet gneiss and grades abruptly into amphibolite at the top. The layered gabbro, considered to be a separate intrusion, is approximately 700 m thick; the layers dip moderately to steeply east. The lower 250 meters consists of interlayered olivine gabbro, pyroxenite, and peridotite. Above this the rocks become more feldspathic but contain two distinct zones of ultramafic rocks. The minerals show no systematic change in composition, although plagioclase in the ultramafic rocks tends to be less calcic (An_{80}) than that in the gabbros ($An_{70\text{-}80}$).

Symplectitic reaction rims of vermicular green spinel in hypersthene and/or diopside separate olivine from plagioclase. In rocks having 35 per cent olivine the symplectite is coarse and composes up to 20 per cent of the rock, but as olivine increases symplectite decreases and is absent in rocks having more than 50 per cent olivine. The symplectite is thought to represent the reaction of olivine with residual liquid to form pyroxene, followed by exsolution of spinel from the pyroxene.

SEQUENCE OF LATE PLEISTOCENE AND RECENT EUSTATIC SEA LEVELS OF THE WESTERN PACIFIC

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Reconstruction of the tectonic history of various islands in the island arcs of the Western Pacific necessitates study of old eustatic shore lines and associated marine-cut notches and marine-cut or wave-built terraces. Correlation among individual islands and among multi-island tectonic zones is the first step in determining the actual sequence of sea-level changes and the "standard" suite of terraces or notches expectable at a hypothetical island that has undergone no secular vertical displacement and has no repetition of terraces by faulting. Pleistocene notches and terraces are generally well preserved by the coralline limestones of islands of the Hawaiian, Mariana, and Caroline groups, but field evidence for the exact sequence of submergences and emergences may nonetheless be obscure. In the Ryukyu Islands, however, terrigenous detrital deposits intercalated with coralline limestones facilitate understanding of transgressions and regressions. Corroboration is provided by correlative deposits and analogous field relations in the Japanese home islands, particularly around Tokyo Bay.

Tentative evaluations of field evidence relating to submarine terraces, emerged terraces, and notches in Tinian in the Mariana Islands, the Miyako Archipelago in the Southern Ryukyu Islands, and the downtown Tokyo area suggest the following sequence of eustatic levels:

+25 feet	Third interglacial?
−50	(Wisconsin?)
−150	(Wisconsin?)
+6	Hypsithermal interval
0	Present

CONCRETE AGGREGATE EXAMINATION BY PROLONGED COPPER-NITRATE STAINING TEST

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When applied over night the copper-nitrate staining test commonly used for distinction between calcite and dolomite has proven very useful for testing concrete aggregates.

The method not only provides means for identification of carbonate rocks or carbonate constituents and secondary carbonate products in silicate rocks, but helps to make the impurities in carbonate rocks, especially clayey material, much more visible. In addition, in argillaceous rock types suspected of being harmful in concrete, scaling, splitting and/or cracking are developed because of expansion. The effect of the test in this respect is analogous to the sodium or magnesium sulphate soundness tests widely used in the appraisal of concrete aggregates, but the former test requires a much shorter time to reveal some of the weak properties in certain rocks (however, not in common silicate rocks) and in addition aids in the identification of the material.

The test may be applied on crushed or uncrushed aggregate particles, on No. 28 sieve size or on parts of drill cores or ledge rock samples.

MICROSEISMS AND THEIR GEOLOGIC APPLICATIONS

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Microseisms, which are prolonged tremors of the earth's crust resulting from storms at sea, appear to have some use in revealing or establishing major submarine structural trends. This seems possible because coherent structural units of the earth's crust act as wave guides for the propagation of microseisms. This propagation effect is very similar to that for the Rg phase of earthquake seismology. Thus, microseisms propagate with very little attenuation from source regions at the Alaskan coast across North America to recording stations in the eastern United States. They also propagate well for long distances along a coast, yet microseisms from storms only a short distance seaward from the continental edge are not felt at coastal stations. Similarly microseisms propagate very poorly across paths transverse to the West Indian Arc, but propagation is much stronger along the Arc. It is possible that microseism propagation effects can establish continuity in island-arc structure between sea-level outcroppings. Studies of propagation across purely oceanic paths are rare, but it is possible that such studies may, in the same way, shed light on the problem of continuity of the oceanic crust.

ANOMALOUS BEDDING ATTITUDES, APPALACHIAN FRONT, CENTRAL PENNSYLVANIA

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Bald Eagle Mountain (and equivalent ridges bearing other names) is the geomorphic expression of the structural Appalachian Front, in Central Pennsylvania or northwestern limit of prominent Appalachian folding. In general, the structure is a northwesterly dipping homocline involving Ordovician and Silurian strata that are bent into a major anticline to the southeast and flatten beneath the plateau to the northwest.

In certain areas, especially in ganister quarries located near the summit of the mountain, southeasterly dips are exposed. These anomalous dips can be explained as overturning by (1) mass movement of weathered rock, (2) drag along a major thrust fault, or (3) folding. Possibility (1) is rejected

on the basis of the thickness of strata involved and the evenness of the overturning for thousands of feet along the ridge. Possibility (2) is rejected because there is no stratigraphic evidence for such a fault, although minor thrusts are probably present near by. Possibility (3) is believed valid because overturning of strata is clearly traceable on the flanks of a few water gaps that cut the ridge.

Especially noticeable in quarries on that part of the ridge known as Dunning Mountain is a major divergence (up to 55°) between the strike of resistant Tuscarora strata and the strike of the ridge crest. Minor transverse faults cut off weaker formations which thus enter the ridge alinement.

EARTH SCIENTISTS IN THE AIR FORCE

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Misconceptions are rampant among earth scientists regarding utilization of their kind by the military. Oft-repeated stories, as of petroleum geologists "logically" made Petroleum Officers in charge of gasoline pumps, are well known. Contrariwise, reports of well-placed men are seldom heard, resulting in a serious professional inferiority complex and defeatism. Therapy is required!

The services presumably will never need earth scientists in the same quantities as physicists and engineers. Nevertheless, there exist limited requirements which are virtually unknown. The Air Force Cambridge Research Center's Geophysics Research Directorate, in addition to principal efforts in atmospheric and astrophysical research, conducts significant studies involving geomagnetism, gravity, seismology, glaciology, ice crystallography and chemistry, oceanography, soils sciences, and civil engineering. Paleontologists and "bedrock" geologists are least critical, but a few find useful administrative positions in terrestrial research programs. Possibilities elsewhere include air photographic interpretation, ground water, installations engineering, and intelligence.

Assuming correct diagnosis, several self cures are indicated. The *profession* must educate the military to a greater potential value of earth scientists. ROTC is recommended for students, since officers (and civilians) receive better assignments. Some outstanding men well versed in mathematics and physics are in demand, but schools must overhaul curricula (emphasizing basic sciences and mathematics) if their graduates would fare well in uniform. Faculty contact with ROTC instructors should promote appropriate specialty classification of cadets, preferably in Research and Development. The Scientific Manpower Commission is eminently successful in obtaining useful assignments; it should be widely publized and patronized.

CONTINENTAL MARGINS AND GEOSYNCLINES, EAST COAST OF NORTH AMERICA NORTH OF CAPE HATTERAS

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Geophysical measurements on the continental margin between Newfoundland and Cape Hatteras have revealed the presence of two sedimentary troughs paralleling the coast. The inner one, under the shelf, contains up to 17,000 feet of sediments which, where drilled, are of shallow-water character. It is separated from the outer trough, under the slope and rise, by a basement ridge which rises to within 5000 feet of the surface of the sediments. The outer trough contains up to 30,000 feet of sediment which cores of the upper part show to be similar to the graywackes of Pettijohn's (1949) classification.

The geometry of this sedimentary system compares very favorably with that of the Appalachian system as restored for the early Ordovician. The sediments of the inner and outer troughs are similar to those of the miogeosynclines and eugeosynclines of Kay (1951), respectively. While there is no

active volcanism in the outer trough at the present time, there is evidence of volcanism in the past. Similar conditions appear to have existed in the Cambrian of the Appalachian eugeosyncline.

The major orogenic process necessary to convert this region to an Alpine-type mountain system is the one which thickens the crust under the eugeosyncline. Since the miogeosyncline is based on a crust of continental proportions, its deformation requires only a means of folding and thrusting the surficial sediments, a process which is but a minor part of the whole tectonic activity involved in building the region into a mountain system.

ELECTRON MICROGRAPHY OF TILLS

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Samples of Wisconsin tills of three ages (50 fragments from each) from northwestern Pennsylvania and northeastern Ohio have been studied under the electron microscope. The materials smaller than 4 microns are almost entirely "masses" of illite and chlorite. These two minerals cannot be differentiated on the basis of morphology shown under the electron microscope, but X-ray diffraction shows that the material is about 60 per cent illite and 40 per cent chlorite. The separate grains range in size from .1 to 4 microns, but the dominant size is <1 micron. Early Wisconsin till ("Tazewell") contains a small proportion of readily identifiable kaolinite in subhedral 1- to 3-micron crystals. Kaolinite is not observed in later Wisconsin ("early Cary" and "late Cary") tills. The clay particles are generally smaller in Cary samples. Quartz particles smaller than 4 microns were observed in only 2 of the 150 fragments. X-ray diffraction analyses of the <1 micron fraction confirm that quartz is very low. No calcite grains were seen in 150 fragments; this confirms X-ray diffraction analyses showing only a trace of calcite in the <2 micron fraction. The <4 micron material in the Wisconsin tills studied is almost entirely illite and chlorite, with exceedingly small amounts of quartz and calcite, but with minor amounts of kaolinite in some early Wisconsin samples. Microfabric is very poorly disclosed, but it is hoped that as techniques are improved it may be more clearly displayed.

PETROGRAPHIC EXAMINATION OF COALS FROM THE ARCTIC SLOPE OF ALASKA

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Petrographic samples were collected during the summer of 1956 from Meade River, Wainwright, and Umiat in Alaska. All the coals sampled are Cretaceous in age and are sub-bituminous in rank.

Thin-section techniques have been used successfully on block and crushed samples. A complete column from Umiat consisting of 20 contiguous samples was prepared. Conditions at the Wainwright area limited collections to the top 8 inches of the seam plus random samples of "run of mine" coal. At Meade River three distinct units of coal were uncovered by trenching. These were collected by channel sampling and in layered samples.

The Meade River coals contain high concentrations of vitrinoid material (all more than 85%) and are exceptionally low in their fusinoid content (0 to 0.2%). The exinoids, particularly cutinite, are abundant in the Wainwright samples.

The Umiat column contains a large percentage of highly mineralized attrital coal. Polarized light is essential for the adequate evaluation of this material. The mineral matter occurs as recognizable grains, as minute particles forming a mixture of clay-sized mineral material and organic matter, and

as fillings in vertically oriented cleats or desiccation cracks. The intimate mixture of clay-sized mineral material and organic matter forms a matrix for the attrital coal of the Umiat samples.

PLUTONIC HISTORY AND ABSOLUTE AGE OF THE HURON CLAIM—JOHNSTON LAKE AREA, SOUTHEAST MANITOBA

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The chronologic and geologic relations of the area between the Winnipeg River and Johnston Lake in southeastern Manitoba have been studied. Field relations indicate that a single plutonic cycle is responsible for both the pegmatites and metamorphic rocks of the region. The measured ages indicate that this event took place 2650 ± 100 m.y. ago.

The major structure of the region is a tightly folded syncline with an east-northeast trend. Metamorphosed pillow lavas to the north form the synclinal trough and are separated from the massive, foliated, pink granite to the south by a 2½–3-mile wide zone of banded biotite migmatites. Quartzites, amphibolites, ultramafic sills, and foliated granite are conformable with and transitional to the migmatites.

Depositional history includes formation of quartz sands, shales, and pillow lavas. Deformation-migmatization followed and was accompanied by the intrusion of white pegmatitic granite and lepidolite-beryl-microcline-quartz pegmatites into the volcanic rocks. Younger mafic rocks in the migmatite zone are represented by discordant partially digested biotite schist bands containing xenoliths of country rocks.

New Rb-Sr dates, calculated from a decay constant of 1.39×10^{-11} yrs.$^{-1}$ for Rb^{87}, are:

Lepidolite	Silverleaf Pegmatite	2680 ± 90 m.y.
Lepidolite	Silverleaf Pegmatite	2670 ± 65 m.y.
Microcline	Silverleaf Pegmatite	2340 ± 140 m.y.
Muscovite	Pegmatite in White Granite Gneiss	2650 ± 45 m.y.
Biotite	Biotite-Granitic Gneiss	2350 ± 66 m.y.

GEOCHEMISTRY OF Sr^{90}

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The detonation of nuclear weapons has resulted in the introduction of Sr^{90} into the atmosphere, hydrosphere, and lithosphere. A consideration of this specific fission product in geochemical processes that occur after deposition on soil is essentially a study of the behavior of calcium and the extent to which its Sr^{90} counterpart lags behind. Before deposition, the geochemistry of Sr^{90} is dependent on meteorological processes that occur below the tropopause and upon the chemical state, concentration, and residence time in the stratosphere.

A suite of New York metropolitan soil samples collected in November 1955 give an average soil concentration of 330 dpm/sq. ft. Rain data indicate a deposition of approximately 1050 dpm Sr^{90}/sq. ft. from November 1955 through March 1957. Repeat soil samples in March 1957 accounted for 940 of the 1050 dpm Sr^{90}/sq. ft., thus supporting the concept that soil data give a true index of fallout rate and concentrations. Vertical-activity soil profiles show that approximately 80 per cent of the Sr^{90} activity is found in the upper 2 inches of undisturbed soil.

Data concerning the levels of concentration, chemical affinity, and geographical variations of Sr^{90} in soil are presented as well as rain data relating the stratospheric storage and tropospheric fallout of Sr^{90} to the presently observed soil concentrations.

HISTORY OF GLACIAL LAKE AGASSIZ*

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The history of Lake Agassiz is reinterpreted from field, literature, and airphoto studies, and radiocarbon dates.

Pre-Wisconsin interglacial deposits underlie till below Lake Agassiz sediments at 12 localities. Wisconsin ice retreated from the lake basin after Mankato time.

Lake Agassiz I resulted from intermittent northward retreat of the ice margin, with readvances in western Ontario; the Dryden-Finlayson-Whitewater moraine represents the advance of the Superior lobe dated at 11,710 years by Wright. The Campbell strand line formed when deepening of the southern outlet was retarded by bedrock. The lake drained eastward, subsiding as ice recession northward from Lake Superior opened successively lower outlets through Brule Creek, Dog River, Kaiashk River, and Pikitigushi River. Disconformities representing the ensuing subaerial interval occur at 24 localities. Little Minnesota River deposited alluvium in the abandoned southern outlet.

Readvancing Valders ice blocked the eastern outlets and formed Lake Agassiz II, 10,500 to 8000 years ago. This lake discharged southward over the alluvial dam, swept it away, and subsided to the lower Campbell strand line. Retreat of Laurentide ice uncovered the lower eastern outlets; then a northern outlet opened between shrinking "Keewatin" and Laurentide ice sheets, perhaps 6500 years ago. Lake Agassiz II drained when residual ice in the Nelson River basin in Manitoba melted more than 3400 years ago.

Bigstone moraine is not Valders as was recently suggested. The Valders ice border probably extended from a moraine west of Lake Nipigon north to Sachigo Lake, west to The Pas, and perhaps northwest to the Cree Lake moraine.

ORIGIN OF WASHBOARD MORAINES†

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Parallel, discontinuous, sandy-silty till ridges (washboard moraines) as high as 15 feet and as long as a mile are spaced 300 to 500 feet apart and form lobate patterns near Cartwright, Manitoba, Canada. Re-entrants between lobes contain "dominant" eskers and outwash. Smaller "subordinate" eskers cross the ridges at low points and commonly change direction or are offset at successive ridges. Till-fabric studies show that they comprise mainly lodgment till, and the preferred orientation of pebbles conforms to the general direction of ice movement inferred from striated boulder pavements and other evidence, rather than to directions locally perpendicular to the ridges.

Probably these ridges were deposited subglacially by lodgment of till at a line (zone) where the brittle upper ice extends down to the sole of the glacier, and where it thrusts against and over a marginal apron of stagnant ice. Subordinate eskers form in the stagnant ice, whereas the dominant eskers between lobes represent major glacier drainage where thinning was more rapid. Melting out of englacial debris furnished sediment for eskers and outwash and formed an insulating layer of ablation moraine that retarded melting of the stagnant ice.

The interval between ridges may represent retreat of the thrust zone and inward widening of the stagnant ice caused by annual glacier thinning; however, annual deposition is not proved. The discontinuity of the ridges may be due to irregularities in the subglacial floor and in amount of glacial debris transported.

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SOURIS BASIN GLACIAL LAKES, SOUTHWESTERN MANITOBA, CANADA*

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In post-Mankato, pre-Valders time, lakes formed against the margin of a retreating ice lobe that flowed southeast, southeast of Moose Mountain. Southeast-trending valleys west of the Souris basin were lateral features. Strandline features are rare; lake boundaries are inferred from lithology, and former levels from the floors and terraces of outlets and from deltas.

First a small glacial lake formed north of Turtle Mountain and discharged east into Pembina River and later southwest into Lake Souris, which was expanding northward. Retreat of the ice margin northwestward to Dand removed the source of this small lake and uncovered an outlet (altitude 1560–1540 feet) through which Lake Souris discharged northeast into the Carroll glacial lake (1520 feet), formed between the retreating Moose Mountain lobe and ice flowing westward up the Assiniboine valley. This lake discharged southeast through Pembina Valley.

Glacier retreat caused the Dand channel to be abandoned, and Lake Souris merged with the Carroll lake; this lake (1490 feet) discharged through Pembina Valley. It was 10 miles wide at the International Boundary and extended only 20 miles into North Dakota.

When Moose Mountain ice withdrew a smaller lake (named for Henry Youle Hind) dammed partly, at first, by Assiniboine valley ice, occupied the Souris basin northeast of Melita. Levels of Lake Hind, indicated by deltas at Melita, Napinka, and Lauder, and by terraces in Pembina Valley, were 1470, 1460, and 1435 feet. Lake Hind drained when the Pembina Valley outlet eroded below 1410 feet.

STRIATED BOULDER PAVEMENTS OF SOUTHERN MANITOBA, CANADA*

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Striated boulder pavements are single horizontal layers of boulders embedded in till with flat upper surfaces in a common plane and bearing glacial striations. They are common north and east of Turtle Mountain and are known elsewhere in Manitoba and southeastern Saskatchewan; they generally bear striations trending southeast. All are overlain by sandy till and are embedded in clayey till except in several instances where compact sand forms the substratum. Structures in the underlying till show that the drag effect of over-riding ice extended only several inches below the pavement surface. The matrix holding the boulders is unleached and commonly unoxidized. Pebble fabric in the overlying till is parallel to the striations. Azimuths of striations at one exposure of 214 boulders ranged from 100° to 160°. Striations on 105 boulders gave a mean of 138° with a standard deviation of ±14°. Striations on a facet greater than 3 square feet in area are almost as reliable as striations on bedrock. Boulder shapes suggest that as much as 6 inches of granite was removed by abrasion ***in situ***.

Boulder pavements form by selective subglacial erosion of till, according to Miller and Gilbert. Cobbles and boulders are pressed into underlying till, or other soft deposit, and smaller particles are removed. The pavements in southern Manitoba represent a single subglacial erosion surface and are probably the subglacial expression of a glacier-regimen fluctuation involving marginal retreat and advance of substage magnitude, perhaps the Mankato-Cary or, probably, the Cary-Tazewell interval.

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ISOTOPIC COMPOSITION OF LEAD IN LEADVILLE LIMESTONE, HYDROTHERMAL DOLOMITE, AND ASSOCIATED ORE

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Leadville limestones were deposited about 250 m.y. ago. Hydrothermal dolomitization and emplacement of associated sulfide ores occurred about 60 m.y. ago. Engel and Engel (1956) have shown that the major and trace-element composition of the unaltered limestone is uniform for many miles. Concentrations of cryptic lead (2–3 ppm) are remarkably constant in both limestone and hydrothermal dolomite. The composition of lead has been determined by Patterson from (1) limestone, (2) hydrothermal dolomite at the edge of the alteration zone and 2 miles away at ore, (3) galena ore. Each sample of limestone and hydrothermal dolomites is a composite of several dozen chips collected across a specific stratigraphic zone. Results are as follows:

Sample	Lead Composition			Lead Concentration (ppm)	Uranium Concentration (ppm)
	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}		
Limestone	21.23	15.83	39.33	1.9	0.4
Hydrothermal dolomite (edge of alteration zone)	22.65	15.91	39.67	n.d.	n.d.
Hydrothermal dolomite (next to ore)	17.93	15.42	37.99	n.d.	n.d.
Galena ore from Gilman mine	17.80	15.58	38.66	n.d.	n.d.

The leads in the limestone and in the hydrothermal dolomite near the edge of the alteration zone are alike. The limestone lead is much more radiogenic than oceanic lead, but there is not enough uranium in the limestone to account for this excess radiogenic lead. Leads in the ore and in the hydrothermal dolomite in contact with ore are identical.

The preliminary results indicate that changes of isotopic composition of lead in carbonate beds by hydrothermal alteration processes accompanying ore mineralization need not be so extensive as other alteration features. The existence of radiogenic lead in unaltered limestone, unsupported by the presence of sufficient uranium, can be accounted for by a separation of uranium from lead either during sedimentation or during subsequent processes which homogenized the limestone.

CHEMICAL DATA ON DESERT VARNISH

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Wet chemical analyses of varnishes, the underlying weathered rinds, and fresh rocks from southern California deserts show that principal varnish elements are O, H, Si, Al, Fe, and Mn. Manganese and Fe give varnish its distinctive characteristics, and Mn is enriched 66 to 292 fold from rock to varnish. Rocks relatively high in Mn and Fe bear the best varnishes.

Quantitative spectrographic analyses of 22 varnishes show that Ti, Ba, and Sr are the most abundant trace elements, followed by Cu, Ni, Zr, Pb, V, Co, La, Y, B, Cr, Sc, and Yb. Cadmium, W, Ag, Nb, Sn, Ga, Mo, Be, and Zn were recorded in some varnishes. Spectrographic analyses of rocks, soils, and air-borne material indicate that variations in trace-element content are related to the local geochemical environment.

Chemical and field data suggest that: (1) varnish on stones seated in soil or colluvium is derived largely from that material, (2) varnish on large bedrock exposures comes from weathered

parts of the rock, and (3) air-borne material is probably a minor contributor.

Desert varnish is primarily a weathering product involving solution, transportation, and deposition of the specified elements. Sources are largely local, and movement can occur by mechanical transport in solution or possibly by ionic diffusion through films of moisture. Dew may be an important source of this moisture. Rate of varnish formation varies widely with local conditions, but at one locality in the Mojave Desert a good varnish has formed in 25 years.

EVALUATION OF THE CHEMICAL AND MINERALOGICAL CHARACTERISTICS OF A URANIFEROUS LIGNITE DEPOSIT FROM HARDING COUNTY, SOUTH DAKOTA

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A study has been carried out to evaluate the variability of the chemical and mineralogical characteristics of a deposit of uranium-bearing lignite using analysis of variance, and simple and multiple regression statistics.

The sampling program was designed to study (1) the vertical variability at each sampling position, and (2) the differences between and within: (a) two lignite seams, and (b) three "zones of weathering" observable in the field within these lignite seams.

Fourteen chemical variables (moisture, ash, uranium, carbon, hydrogen, total sulfur, sulfide sulfur, sulfate sulfur, total iron, HCl (1:1) soluble iron, silicon, aluminum, calcium, magnesium) were determined by wet-chemical, absorption-spectroscopic, and x-ray fluorescence methods. Mineralogical investigations were carried out by x-ray diffraction.

On the basis of analysis of variance of the carbon values only two "zones of weathering" could be distinguished, rather than the three observed in the field. The distribution of the other variables within and between zones and seams will be discussed.

By using simple and multiple-regression statistics to evaluate the complex interrelationships of the 14 variables measured, it was found that the variation of carbon, hydrogen, total iron, and aluminum probably plays no significant role in determining the variation of uranium, while the variation of moisture and calcium is closely associated with the variability of uranium.

SILICIFIED MIDDLE ORDOVICIAN TRILOBITES, FAMILY ENCRINURIDAE

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The trilobite family Encrinuridae is represented in the Middle Ordovician of Virginia by silicified remains of 10 species and 3 varieties distributed among 6 genera and 3 subfamilies. Eight species, 3 varieties, 2 genera, and 1 subfamily are new. Ontogenetic stages from protaspis to holaspis are known for at least 1 species in each subfamily; 5 of the 6 genera are represented by abundant meraspid and holaspid parts. This large suite of specimens affords an unusual opportunity to make a detailed comparative study of morphology, ontogeny, and phylogeny in a group of closely related trilobite taxa. Simple but distinctive segmental ornament and other useful "landmarks" identifying homologous shell areas facilitate the study. Typical of results is an analysis of relationships of the glabella: In the Encrinuridae the glabella shows a conspicuous tendency to inflate and expand beyond its usual limits, invading and incorporating areas primitively a part of the cheek or anterior border. In subfamily Cybelinae, *Cybeloides* and *Bevanopsis* show slight glabellar inflation but marked forward and lateral expansion; the conspicuous lateral lobes of adults are in reality parts of the cheeks. In subfamily Encrinurinae, glabellas of *Encrinuroides* and new genus A are inflated and moderately expanded forward into the anterior border, but restricted laterally by the primary dorsal furrow. Longitudinal enlargement and general glabellar inflation reach maxima in new genus B (new subfamily) whose median glabellar profile from occipital furrow to posterior extremity of hypostome is a strongly convex curve uninterrupted by furrow or ridge.

THEORY OF ICE AGES—PART II

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Pleistocene glaciation in the southern hemisphere was for the most part only a moderate extension of existing glaciers and is usually assumed to have been in phase with the major glacial advances in the northern hemisphere. The areas affected were high mountain regions, small islands in the southern ocean, and small parts of the Antarctic coast. The only major climatic change in the southern hemisphere was that recorded by the formation of the Antarctic icecap, probably at the beginning of Pleistocene. All other Pleistocene climate changes in the southern hemisphere were thus minor in comparison with those of the northern hemisphere, consistent with the theory (A Theory of Ice Ages, Science, 123, 3207, 1956) that the fundamental cause of the glacial-interglacial cycles is to be found in the northern hemisphere.

Moist or pluvial periods, which have been proven contemporaneous with the last glacial cycle by radiocarbon dating, were probably contemporaneous with all of the glacial stages. All major desert areas of the world were fertile and lake-covered, apparently, during each glacial stage.

The increased rain of the pluvial stage which can be explained by a modification of the primary atmospheric circulation brought about by the presence of continental ice sheets is barely secondary in importance to glacial advances as an index of climate change. This is consistent with the theory that terrestrial changes bringing about an increase in precipitation were responsible for the major climatic fluctuations of the Pleistocene.

REGIONAL MEASUREMENTS OF CRUSTAL THICKNESS

Maurice Ewing and Frank Press
For abstract *see* page 1816

AGE OF NOVA SCOTIA GRANITES

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A reconnaissance age investigation of the pre-Carboniferous granites of Nova Scotia has been carried out using Sr and A methods on biotite, muscovite, and potassium feldspar. Forty-three analyses from 28 localities, extending the entire length of the province (about 400 miles), indicate post-Cambrian intrusions only. Eighty-five per cent of the ages determined lie between 330 and 395 m.y.; the youngest is 325, and the oldest 430 m.y. Agreement between Sr and A analyses is better than 10 per cent. It is uncertain as yet if only one, or possibly two, stages of intrusion are represented. Based on Holmes' time scale, and on supporting evidence from glauconite ages of Cormier (1956) and Lipson (1956), most of the Nova Scotia granites would appear to be Silurian or Ordovician. Field evidence however in two localities, Nictaux and Bear River, indicates post-Lower Devonian granite intrusion. Work is still in progress in an effort to resolve this problem.

SUBSOLIDUS PHASE RELATIONS IN THE ALKALI FELDSPARS

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In a recent paper Ferguson, Traill, and Taylor (Acta Crystallographica, in press) give evidence which suggests strongly that electrostatic charge controls the Al-Si distribution in stable low albite. Their application of this principle to the potassium feldspars led them to two conclusions of great

importance to the subsolidus phase relationships in the alkali feldspars: (1) The most balanced potassium feldspar structure is partially ordered with respect to Al-Si, and monoclinic—orthoclase. (2) The triclinic microclines probably originate as the exsolution products of alkali feldspars which cooled from fairly high temperatures and which, at those high temperatures and before exsolution, contained appreciable Na with the K, the Na conferring on the framework triclinic symmetry which persists following perthitic exsolution at lower temperatures. The potassium feldspar series orthoclase—intermediate microclines—maximum microcline is thus accounted for by the presence of increasing Na with the K before exsolution. An important consequence of this theory of origin of microcline is that, after perthitic exsolution, the sodium feldspar component too must have a tetrahedral framework inappropriate to it, and there must exist a series of sodium feldspars analogous to the microclines, ranging from low albite at the pure sodium end to a "maximum albite" at the high potassium end. For the intermediate sodium members the author tentatively suggests the term *interalbite*.

According to these ideas, the room-temperature phases on the alkali feldspar phase diagram would be: orthoclase; orthoclase + maximum albite; intermediate microcline + interalbite; maximum microcline + low albite; low albite.

EXTENSIVE PROGLACIAL LAKE OF WISCONSIN AGE IN THE COPPER RIVER BASIN, ALASKA

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Strand lines and glacio-lacustrine deposits in the northeastern Copper River Basin demonstrate the existence of a proglacial lake with maximum extent of 1000+ square miles. Stratigraphic evidence, supported by radiocarbon data, indicates a Wisconsin age.

Numerous glaciers exist in the high mountains surrounding the Copper River Basin. The Copper River, draining most of the basin, flows through the Chugach Mountains into the Gulf of Alaska. During early Wisconsin time, glaciers dammed the river and formed a lake within the basin.

Locally prominent strand lines at approximately 2450, 2300, and 2150 feet above sea level, and less prominent shore lines at intermediate and lower levels, indicate periods of relatively stable lake level, separated by periods of fluctuant lowering of lake level.

The glacio-lacustrine deposits include rhythmically bedded and massive fine sand, silt, and clay; commonly they contain scattered ice-rafted pebbles, cobbles, and boulders and grade laterally into thin-bedded, well-sorted sand and gravel.

Radiocarbon-dated organic samples from below and above the glacio-lacustrine deposits bracket the time of the lake's existence between greater than 38,000 years (W-531) and 4610 ± 200 years B.P. (W-297). Samples W-429 and W-487 date an interval of low lake level between 11,440 ± 200 and 9240 ± 300 years B.P., preceded and followed by periods of higher lake level.

Although lake level fluctuated in response to climatic change and fluctuating ice fronts, the lake existed throughout most of Wisconsin time and drained either during glacial retreat in late Wisconsin time or during the post-glacial period of maximum warmth.

PRE-ONATE DEFORMATIONS IN SOUTHERN NEW MEXICO

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Sections in Rhodes Canyon, San Andres Mountains, New Mexico, indicate two periods of deformation following Cutter (late Montoya and late Richmond) deposition, and preceding Onate deposition, of latest Middle or earliest Late Devonian age. The first developed small faults and folds, displacing the Montoya surface; later peneplanation so beveled the surface that it varies er-

ratically from 58 feet above the base of the Cutter to 24 feet below it in less than an eighth of a mile. A second faulting may be connected with the subsidence permitting invasion of the Onate seas. Faults displace the already truncated Montoya surface, and the Onate is deposited on the resulting irregular surface. Local erratic variations in Onate thickness from 6 feet to 28 feet result.

Exceptional exposures are required for identification of the pre-Onate structures, owing to extensive Laramide to Recent movement in the region. Nevertheless both pre-Onate disturbances were widespread over southern New Mexico. Local but less extreme variations in Montoya thickness in other sections suggest the first disturbance. Both local and general thickness variations in the Onate involving its deposition on an uneven surface require the second movement in view of evidence of earlier peneplanation.

Clearly, pre-Laramide movement in southern New Mexico was not purely epeirogenic, as formerly believed. Small structures in older sediments require close examination, as some may date from these pre-Onate disturbances, or from the post-Morrow one recently recognized in northern New Mexico, rather than from Laramide or Cenozoic deformation.

STRUCTURAL GEOLOGY OF THE PERIMETER OF THE BEARTOOTH MOUNTAINS, MONTANA

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The Beartooth Mountains are a topographically and structurally elevated crustal block of crystalline rocks about 80 miles long and 30 miles wide. Situated in the middle Rocky Mountains east of the great north-south belt of overthrusts, the Beartooth Mountains are bounded on the east by the Bighorn Basin with an average structural relief of 15,000 feet; on the northeast and north by the Nye-Bowler lineament (dominantly left-lateral movement); on the north by the Crazy Mountain syncline with an average structural relief of at least 10,000 feet. Most of the southwest side of the block (Yellowstone-Absaroka Mountains) is covered by thick Tertiary volcanic rocks that mask structural detail.

A thrust plane(s) dipping west-southwest along the east-northeast border is the major structural feature between the Clarks Fork of Yellowstone River and Nye village. Near Red Lodge, Montana, where the mountain border bends, numerous tear faults displace the upper plate of the thrust as much as 10,000 feet. From Nye to Livingston the major bounding structure is a north-northeast dipping thrust plane(s) terminating at the west in several left-lateral tear faults. Near Gardiner, Montana, a high-angle thrust plane dipping northeast bounds part of the southwestern Beartooth.

Field evidence supports the idea that Laramide orogeny involved primarily vertical upward movement of the crystalline block along old Precambrian fractures while the overlying sedimentary veneer, in a passive role, draped, broke, and slid along the high-angle thrusts of the frontal edge.

GEOCHEMICAL STUDY OF SOME LATE WISCONSIN TILLS

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Samples of unleached, late Wisconsin tills were collected from moraines deposited by the Des Moines, Lake Michigan, Saginaw, and Erie ice lobes. The combined silt-clay fractions were analyzed spectrographically for major and minor chemical constituents.

The Des Moines lobe tills are higher in Zr, Ba, and Mn and lower in Sc than are those of the other lobes, while the Lake Michigan lobe tills are characterized by high Ti and Al and low Sr. The tills of the Saginaw and Erie lobes have notably higher concentrations of Ca and Sr than are found in either the Des Moines or Lake Michigan tills. In addition, the V content of the Erie lobe tills is also higher than that of the others.

As a result of the investigation the following conclusions are reached:

(1) The silt-clay fraction of moraines deposited by an individual ice lobe are chemically homogeneous.

(2) When geomorphic and sedimentologic factors are considered, the chemical composition of the fine fraction of tills may be used to differentiate tills having different source areas.

(3) Local bedrock changes have had little, if any, effect on the chemical composition of the tills studied, and probably the greater portion of them has been derived from distant source areas.

"EARLY" WISCONSIN DRIFT IN OHIO

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Drift of "early" Wisconsin age, defined by R. P. Goldthwait as that Wisconsin-age material lying beneath a buried soil of rather extensive occurrence, has been recognized at a number of localities in midwest Ohio; radiocarbon dating shows it to be >37,000 years old. The buried soil was formed in gravel in almost every case and appears very much like the modern soil developed in gravel; the buried soil in the Sidney cut, developed in till, is interpreted to be of this age.

"Early" Wisconsin drift has been identified at the surface in some areas by the presence of unusually deep and weathered soil profiles, developed in till in Highland County and in gravel in the Hocking River valley. It is significant that the investigations in these two areas and the decisions to assign to these deposits an "early" Wisconsin age were entirely independent.

The "early" Wisconsin as defined in Ohio is believed to represent the same earlier shorter substage of the Wisconsin reported by Ericson and by Zeuner.

1957 EXPLOSIVE ERUPTION ON IWO-JIMA, KAZAN-RETTŌ

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An explosive eruption occurred without warning on March 28, 1957, near the center of Iwo-Jima, a small volcanic island midway between Guam and Tokyo, Japan. The eruption of steam, volcanic sand, and volcanic sandstone and conglomerate blocks began suddenly at 11:55 a.m. local time, continued for 65 minutes, and ended abruptly. Coarse ejecta were thrown as high as 150 feet; dust and steam rose to heights of 200 to 300 feet. No juvenile material was ejected. An elliptical crater 90 to 110 feet in diameter and 45 feet deep resulted. Deposits were concentrated to the western (lee) side where they ranged in thickness from 22 feet near the crater to less than 1 inch 300 feet to the west. About 50 minutes after the eruption a second crater formed by collapse 75 feet west of the eruption crater. The circular collapse crater was 115 feet in diameter and 55 feet deep. Many ground cracks and small faults with displacements up to 8 inches were formed near by during and following the eruption. Steam and other gases issued from the craters, faults and cracks following the eruption, and some sublimates were deposited. No significant change of fumarolic activity was noted on other parts of the island before, during, or after the eruption.

The eruption resulted from the sudden release of an underground accumulation of steam under high pressure beneath fill adjacent to an abandoned air field. The eruption does not seem to indicate an increase in volcanic activity on Iwo-jima.

INTERPRETATION OF THE COMPOSITIONS OF TRIOCTAHEDRAL MICAS

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Phlogopite, in its ideal form $Mg_{3.0}(Si_{3.0}Al_{1.0})O_{10}(OH)_2K_{1.0}$, can be considered the prototype of the trioctahedral micas, just as muscovite, in its ideal form $Al_{2.0}(Si_{3.0}Al_{1.0})O_{10}(OH)_2K_{1.0}$, is the prototype of the dioctahedral potassium micas. The composition of all trioctahedral micas can be interpreted as derived from phlogopite by the proxying of other cations such as Fe^{+2}, Fe^{+3}, and Al, for Mg. In phlogopites the proxying of such cations for Mg is minor, and Mg occupies more than 75 and as much as 98 per cent of the octahedral positions. In Mg-dominant biotites Mg is also the dominant octahedral cation, but there is greater octahedral occupancy by other cations than in phlogopites. In Fe^{+2}-dominant biotites octahedral occupancy by other cations is still greater; the amount of Fe^{+2} proxying for Mg is so great that it is dominant over Mg. However, in all these micas there is multiple proxying of other cations for Mg, not proxying by one alone. Consequently the low Mg trioctahedral micas are not annites, $Fe_{3.0}^{+2}(Si_{3.0}Al_{1.0})O_{10}(OH)_2K_{1.0}$, the Fe^{+2} analogue of phlogopite postulated by Winchell, and for whose existence published analyses furnish no evidence, but are siderophyllite, $(Al_{0.5\text{-}1.0}Fe_{2.4\text{-}1.6}^{+2})(Si_{2.7}Al_{1.3})O_{10}(OH)_2K_{1.0}$, and its ferric analogue, lepidomelane, $(Fe_{0.5\text{-}1.0}Fe_{2.4\text{-}1.6}^{+2})(Si_{2.7}Al_{1.3})O_{10}(OH)_2K_{1.0}$. Thus the trioctahedral micas can be considered as members of a complete system, at one end of which is phlogopite, with essentially complete octahedral occupancy by Mg, and at the other end of which is siderophyllite and lepidomelane with essentially zero octahedral occupancy by Mg.

EVIDENCE OF ICE-JACKING IN NORTHERN NEW HAMPSHIRE AND VERMONT

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During the construction of the Samuel C. Moore hydroelectric project on the upper Connecticut River in New Hampshire and Vermont, near Littleton, New Hampshire, considerable evidence of ice-jacking was disclosed in the excavation. Observations limited to the excavated area revealed a remarkable series of gently dipping, parallel, plane, silt- and sand-filled joints or cracks extending 500 feet along the strike and extending to a maximum depth of 70 feet below the original surface in an unweathered soda rhyolite of the Ammonoosuc Volcanics. The joint-filling material is glaciofluvial in origin and ranges from a maximum thickness of 1 foot at the outcrop of the joints to less than a quarter of an inch at the maximum depth. Plucking by the overriding ice sheet and filling by subglacial streams may have had a part in the action, but a detailed study of the joints shows that ice-jacking was the most important action.

EARLY TERTIARY, VINCENTOWN, MANASQUAN, AND SHARK RIVER FORAMINIFERA FROM CORES IN THE NEW JERSEY COASTAL PLAIN

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Recent studies of Foraminifera from cores in the New Jersey Coastal Plain reveal three distinctive faunas in the Vincentown, Manasquan, and Shark River formations. Surface exposures of the Manasquan and Shark River have to date yielded only fragmentary remains.

The Vincentown fauna contains many species in common with the Salt Mountain Formation in Alabama and with the Aquia of Maryland. It contains many planktonic species identical with

uppermost Hornerstown forms which suggests post-Thanetian pre-Ypresian age for the Vincentown. This interval in Western Europe is occupied by the Sparnacian. The Sparnacian contains *Hyracotherium* and *Coryphodon* which are diagnostic Lower Eocene species of mammals. Benthonic Foraminifera in the Vincentown limesand differ sufficiently from those in the underlying Upper Hornerstown greensand to indicate facies control.

Planktonic species dominate the Manasquan fauna which occurs in greensand. They resemble Ypresian forms and apparently indicate equivalence of the Manasquan to part of the Wilcox of the Gulf Coast.

The Shark River contains many species restricted on the Gulf Coast to the Claiborne (Middle Eocene). The abrupt reappearance in the Shark River of many benthonic species of the family Lagenidae suggests a return to conditions similar to those which existed during the deposition of the regressive Vincentown.

ORIGIN OF WATER IN SOME VOLCANIC GLASSES

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The deuterium-hydrogen composition (relative to Lake Michigan water = 0.0) of water extracted from coexisting perlite and obsidian from 11 different localities was determined. The water content of the obsidians is generally from 0.08 to 0.35 per cent by weight, though two samples from near Olancha, California, contain 0.98 per cent. The relative deuterium concentration is from −4.6 to 11.0 per cent. The coexisting perlite contains from 2.0 to 3.9 per cent of water with a relative deuterium concentration of −3.2 to −13.8 per cent. The deuterium concentration in the perlites is not related to that in the enclosed obsidian. The deuterium concentration in the perlite water is related to the deuterium concentration of the modern meteoric water, and the perlite water contains approximately 4.0 per cent less deuterium than does the ground water. The above relationships hold true for perlites from Iceland, northern New Mexico, Mojave desert, east slope of the Sierra Nevada, Coast Range of California, Saipan, and New Zealand. As the water in the obsidian is unrelated to meteoric water, but the enclosing perlite water is related, we believe that this is evidence for the secondary hydration of obsidian to form high-water-content perlitic glass.

An examination of obsidian artifacts from archaeological sites shows visible hydration of specimens estimated to be 500 years old. A sample dated by C^{14} as 2000 years old shows hydration. This is proof of the hydration of obsidian at atmospheric temperature and pressure.

DISTRIBUTION, THICKNESS, AND ORIGIN OF SINUOUS SANDSTONE LENSES OF THE ALLEGHENY SERIES, VIGO COUNTY, INDIANA

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Data from 60 drill holes and 10 outcrops delineate 2 sinuous sandstone lenses that extend southwest 5–6 miles from the Wabash River Valley in northern Vigo County, Indiana. Each lens has a base that is convex downward and a level top that dips 25 feet per mile southwest. Tributary sandstone lenses trending southwest join the main sinuous lenses and form a dendritic pattern. The sandstones occur between Indiana Coals Vb and VII in the Dugger Formation of the Allegheny Series. The sandstone lenses overlie gray shale, probably unconformably, and underlie conformably either thin limestone, or shale, or the underclay of Coal VII. Laterally the sandstones probably intertongue with gray shale.

One sandstone lens attains a thickness of 90 feet where its top width is 2500 feet. The sandstone is thickest at the center of the channel-like lenses and thinnest at the sides. The two main

lenses are within half a mile of each other laterally, 225 feet below the upland at the Indiana-Illinois State line, and they probably coalesce a mile southwest of this line.

Three hypotheses are considered to explain the origin of the sinuous lenses. The sandstones (1) originated as offshore bars, (2) are filled delta distributaries, or (3) are filled terrestial stream channels. The first two are invalid because the sandstones have a dendritic pattern, thicken in the direction of the regional dip, have an even top and a base that is convex downward. These facts best fit the third hypothesis.

POLYMORPHISM IN CRONSTEDTITE

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A study by Weissenberg and precession x-ray single-crystal methods has shown that polymorphism is common in the kaolinite-type phyllosilicate cronstedtite, $(Fe^3, Fe^2, Al, Ca)_{4-6}(Fe_2^3, Si_2)_4 O_8(OH)_{10}$. Three polymorphs in addition to the original 3-layer rhombohedral structure described by Hendricks in 1939 were recognized: (1) A 1-layer hexagonal polymorph with $a_0$5.49 kX, $c_0$7.08; from Nye County, Nevada; Kuttenberg, Bohemia; Kisbanya, Roumania; Llallagua, Bolivia; Wheal Jane, Cornwall. The material from Kisbanya described by Gossner (1935) probably belongs here. (2) A 2-layer hexagonal polymorph with $a_0$5.49, $c_0$14.16; from Llallagua; Prizbram, Bohemia; Eisleben, Germany. (3) A 9-layer rhombohedral polymorph, with $a_0$9.54, $c_0$63.72 in hexagonal co-ordinates; from Kuttenberg, Cornwall, and Nevada. (4) The original 3-layer rhombohedral polymorph has $a_0$5.48, $c_0$21.25 in hexagonal co-ordinates; from Kuttenberg.

Stacking disorder is particularly marked in the Cornwall 9R material, with diffuse scattering in zones with constant h and k indices, variable l, and h not a multiple of 3, caused by random displacements of $na/3$. All four polymorphs have marked pseudo-cells with $a_0$3.18 kX and different c axes: $c_0$7.08 (1H), 14.16 (2H), 21.25 (3R), and 21.24 (9R). The pseudo-cell and its 90° rotation around the c axis relative to the true cell in the 1H, 2H, and 3R polymorphs originates in the ordered, alternating 1:1 distribution of Fe^3 and Si in the tetrahedral framework. In the 9R polymorph the true and pseudo-cells are oriented parallel, at 90° to the other polymorphs, and the tetrahedral Fe^3 and Si are believed to be either disordered or randomized by stacking.

ELECTRICAL PROPERTIES OF SOME SULFIDE MINERALS

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The width of the energy gap between the valence band and the conduction band of semiconducting sulfide minerals can be determined from the resistivity *vs.* temperature curves at temperature ranges where the minerals become intrinsic semiconductors. The resistivity *vs.* temperature curves of chalcopyrite and pyrite were determined. Chalcopyrite shows a slow increase in resistance with temperature until 280°C. Above this temperature the resistivity rapidly decreases with increasing temperature. A similar reversal has been observed by others as well as by the author in some types of pyrite crystals at about 385°C. The failure of any of the pyrite or chalcopyrite samples to recover their resistance upon cooling indicates that the rapid decrease in resistivity observed is not due to intrinsic semiconductivity alone but to an increase in the number of carriers due to a chemical change. (Dissociation: $FeS_2 \rightleftharpoons FeS_{2-x} + S\uparrow + \text{hole}$).

Further attempts are being made to determine the energy gap width by measurements of the variation of Hall effect with temperature at temperatures below those at which these minerals rapidly dissociate at low-sulfur vapor pressures.

SOME FREE-ENERGY VALUES FROM GEOLOGIC RELATIONS

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Mineral associations in earth-surface environments have been used to obtain basic thermochemical data for reactions and compounds of geologic interest. From a study of weathering processes, standard free energies of formation from the elements at 25°C. and 1 atmosphere total pressure have been estimated for kaolinite (−883 kcal.), muscovite (−1298 kcal.), and K feldspar (−856 kcal.). From relations in the zone of oxidation of ore deposits a correction has been made to the published value for Hydrocerussite (from −409.1 kcal. to −406 kcal.) and a new value determined for malachite (−217 kcal.). It is suggested that the methods used can be applied to obtain useful free-energy values for many other compounds.

STABILITY OF URANIUM, VANADIUM, COPPER, AND MOLYBDENUM MINERALS IN NATURAL WATERS AT LOW TEMPERATURES AND PRESSURES

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Stability diagrams covering the range of natural conditions at low temperature and pressure have been constructed for systems involving a metal (U, V, Mo, Cu), water, oxygen, carbon dioxide, and sulfur. It appears that there is a restricted set of conditions under which all four metals have a solubility of more than a few parts per million in a medium resembling natural ground water. Chief requirements for mutual solubility are moderate to strongly alkaline and mildly reducing conditions and a partial pressure of $CO_2 > 10^{-1}$ atmosphere. Higher solubility in this environment results from formation of uranium di- and tri-carbonate complexes, a copper di-carbonate complex, vanadite ions, and molybdate ions. Under more oxidizing conditions insoluble vanadates appear, including the uranium vanadates, carnotite and tyuyamunite; under more reducing conditions insoluble oxides and sulfides form.

For deposits in sandstone containing these four elements, it seems likely that transportation took place under the conditions given above. Deposition of typical black uranium ores would be favored by decrease in pH and oxidation potential. The mineral species expected would be uraninite, umohoite, montroseite, copper sulfides, and molybdenite. Data for silicate minerals are lacking.

ABSOLUTE AGE DETERMINATIONS FROM THE BASEMENT ROCKS OF THE BEARTOOTH MOUNTAINS AND BIGHORN MOUNTAINS

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The ages of several micas and feldspars from the southeastern part of the Beartooth uplift and the northern Bighorn uplift have been measured using the Rb-Sr and K-A methods. Both pegmatitic and separated minerals were examined. Apparent ages derived from measurement of Sr^{87}/Rb^{87} and A^{40}/K^{40} ratios are given below. These ages are based on a decay constant of 1.39×10^{-11} yr.$^{-1}$ for Rb^{87}; $\lambda_B = 4.8 \times 10^{-10}$ yr.$^{-1}$ and $\lambda_e = 0.58 \times 10^{-10}$ yr.$^{-1}$ were used for K^{40}.

The K-A ages appear consistently lower than the Rb-Sr ages. This is interpreted as an indication of argon loss.

It is concluded that the metamorphic event forming the pegmatites and gneisses of these areas took place 2750 ± 150 m.y. ago.

Sample	Rb-Sr (m.y.)	K-A (m.y.)
Beartooth Mountains		
Muscovite, Christmas Lake Pegmatite	2800 ± 50	2470 ± 50
Microcline, Christmas Lake Pegmatite	2770 ± 100	
Muscovite, Blackstone Lake Pegmatite	2700 ± 70	2530 ± 50
Biotite pegmatite in Quad Creek Norite	2530 ± 50	2310 ± 60
Microcline pegmatite in Quad Creek Norite	2730 ± 70	
Granite gneiss, Biotite	2750 ± 60	2360 ± 50
Shoshone Gorge		
Biotite	2720 ± 65	
Bighorn Mountains		
Granite Gneiss	2760 ± 70	2560 ± 50

REGIONAL GEOLOGY OF THE WABUSH LAKE AREA, WESTERN LABRADOR

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Wabush Lake is located in the metamorphosed southeastern elbow of the "Labrador Trough" and lies on the trend of the so-called "Grenville front".

The older Precambrian terrane of this area consists of metamorphosed and deformed granite, granitic gneiss, and feldspathic biotite gneiss. Lying unconformably upon this is a sequence of younger Precambrian rocks: biotite schist, diopside-tremolite marble, quartzite, muscovite schist, metamorphosed sedimentary "iron formation", coarse-grained kyanite-bearing muscovite schist, and calcareous, graphitic amphibolite. The "iron formation" has a maximum stratigraphic thickness of the order of 700 feet and includes oxide-, silicate-, carbonate-, and sulfide-iron facies.

Following the deposition of younger Precambrian rocks the entire area was regionally metamorphosed and strongly deformed. Two axes of folding are prominent, one trending north to northwest, and the other northeast (parallel to the Trough). Following, and possibly during, dynamothermal metamorphism the area was intruded by gabbroic rocks. This intrusion was accompanied by hydrothermal metamorphism of the intruding rock, forming amphibolite, and by static thermal metamorphism of the intruded rock, producing rocks of granular texture.

TERTIARY BRECCIA PIPES IN THE SHOSHONE RANGE, NEVADA

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Near the crest of the Shoshone Range in north-central Nevada, three vertical breccia pipes of Tertiary age cut deformed chert, quartzite, shale, and greenstone of Paleozoic age. The pipes are about 1 mile in longest dimension, have slightly flaring sides, and consist of the following units: (1) an outer rim of coarse breccia of Paleozoic rock fragments; (2) an inner mass of fine-grained and much hydrothermally altered breccia that contains a thorough mixture of Paleozoic and Tertiary rock fragments and intrudes the marginal coarse breccia; (3) foundered blocks of Tertiary conglomerates and pyroclastic rocks intruded and engulfed by the fine breccia; (4) a central plug

of quartz monzonite porphyry that intrudes the fine breccia; (5) narrow flow-banded dikes of rhyolite and quartz latite porphyry that cut all other rock types in the pipes and extend into the wall rocks.

The pipes were formed by an up-and-down pump action impelled by intermittent rise of the quartz monzonite magma. Brecciation occurred during upward movement of the magma and associated explosive volcanism. Breccia also was formed by subsidence, collapse stoping, and possibly rock bursting during subsidence of the magma. The fine breccia thus formed ahead of the magma and in turn became intrusive, eventually working its way to the surface.

ENVIRONMENTAL MAPPING OF THE ST. DAVID CYCLOTHEM, EASTERN AND WESTERN INTERIOR COAL BASINS

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The St. David cyclothem, of late Desmoinesian age, consists of basal sandstone, sandy shale, underclay limestone, underclay, a very widespread and valuable coal (No. 5 of Illinois and Indiana, No. 9 of Kentucky), local gray shale, widespread black fissile shale, marine limestone and calcareous shale, and upper gray shale with clay ironstone nodules and bands, the Canton shale. In much of the area these beds are directly overlain by strata of the Brereton cyclothem, but, in the deeper part of the Eastern Interior basin, an additional series of strata including basal sandstone, underclay, coal, dark shale, marine limestone, and upper gray shale are intercalated between the two widespread cyclothems.

The details of lithologic sequence of this cyclothem and the geographically restricted one overlying it have been recorded from outcrops, mines, diamond-drill cores, electric logs, sample studies, and drillers' logs in about 700 townships in Illinois, Indiana, western Kentucky, Missouri, Kansas, Oklahoma, and Iowa. Environmental maps have been made for the times of deposition of the basal sandstone, underclay, coal, black fissile shale, marine limestone, and upper gray shale. An isopach map shows that the intercalated cyclothem thickens southward with a maximum thickness of more than 50 feet in southern Illinois and western Kentucky.

These maps give evidence as to the rapidly changing depositional environments during a single cycle of sedimentation, and as to the sources of clastic sediment, direction of marine overlap, and the relations to downwarping basins and weak positive areas such as the Missouri Ozark Mountains.

STRATIGRAPHY OF THE MIDDLE PART OF THE UPPER CRETACEOUS MATAWAN GROUP IN THE NEW JERSEY COASTAL PLAIN

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Foraminiferal studies of the Matawan Group include surface and subsurface exposures of the Woodbury, Merchantville, Englishtown, and Marshalltown formations.

Absence of a varied neritic fauna, a predominance of species of the family Lituolidae, and the generally sandy lithology of these formations suggest near-shore environment in the northern half of the Coastal Plain. The presence in the southern part of the Coastal Plain of large and diversified microfaunas represented principally by species of the families Lagenidae and Anomalinidae indicates a change to more typical neritic conditions. The Woodbury fauna in the northern part of the Coastal Plain shows a similar change down-dip from a restricted arenaceous assemblage in surface exposures to diversification of species in well samples.

Comparison with Gulf Coast Foraminifera indicates correlation of the Woodbury, Merchantville, Englishtown, and Marshalltown with the Taylor.

TRANSCURRENT FAULT AND OVERTURNED THRUST, SHOSHONE RANGE, NEVADA*

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The Roberts thrust (post Early (?) Mississippian) in north-central Nevada brings clastic and volcanic rocks of Ordovician, Silurian, and Devonian age over carbonates of Cambrian to Early Mississippian age. Windows prove a minimum displacement of 50 miles. The most westerly window known, at Goat Ridge in the Mt. Lewis quadrangle, is here described.

A near-vertical left-lateral rift extends about 8 miles east from the window to a Tertiary intrusive mass, where it is lost. The rift offsets the east edge of the window about 2 miles but extends no farther west in either plate. South of the rift the thrust upwarp is open; north of it the east limb of the upwarp is inverted; the lower plate overlies the upper at dips as low as 35°. Farther north this overturned fold in the thrust becomes isoclinal, with its brow a hairpin curve with radius less than 100 yards. Near and at this overturn, five successively younger and structurally higher branches spring from the Roberts thrust and show decreasing involutions upward.

North of the rift the thrust scales constituting the upper plate are thrown into close folds, some isoclinal; south of it, folding in the upper plate is much more open. This difference is attributed to a steep northward plunge of the thrust near the rift line, with relative blocking of the thrust advance on the north. Thus the plunge and overturning of the thrust, the isoclinal folding of the upper plate, and the rift all developed concurrently.

EQUILIBRIUM BETWEEN THE METASILICATES AND ORTHOSILICATES OF MAGNESIUM AND MANGANESE

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Redetermination of the melting point of tephroite (Mn_2SiO_4) and rhodonite ($MnSiO_3$) in an atmosphere of controlled P_{O_2} shows the former melting congruently at 1345°C., the latter melting incongruently to silica + liquid at 1292°C. Forsterite (Mg_2SiO_4) and tephroite form an unbroken series of solid solutions.

Inasmuch as the compound $MgSiO_3$ melts incongruently to forsterite + liquid, the metasilicate join exhibits a reversal in type of incongruent melting. Metasilicate compositions in the range 13–78 per cent $MnSiO_3$ melt congruently. Rhodonite solid solutions extend from $MnSiO_3$ to 95 per cent $MgSiO_3$ at solidus temperatures, the extent of solid solution decreasing to 78 per cent $MgSiO_3$ at 1300°C. A very narrow two-phase region (high enstatite s.s. + rhodonite s.s.) is present.

The high enstatite-rhombic enstatite inversion could be realized using hydrothermal techniques.

Equilibrium between coexisting olivines and metasilicates is discussed. In general, the olivine phase is richer in manganese than the coexisting metasilicate phase.

STRUCTURAL AND COMPOSITIONAL VARIATIONS IN SOME NATURAL DOLOMITES

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Dolomite fractions concentrated from Cretaceous and younger rocks from Florida, Texas, Venezuela, Eniwetok, Funafuti, Kita Daito Jima, and other localities deviate compositionally and struc-

* In cooperation with the Nevada Bureau of Mines.

turally from the ideal compound. Powder X-ray diffraction spacings indicate that these materials in general contain more than 50 mol per cent $CaCO_3$ in their structure. The most Ca-rich natural dolomites yet observed are from the western Pacific islands and contain approximately 5 mol per cent excess structural $CaCO_3$. Spectrographic analysis shows these dolomites to be very low in Fe and Mn.

Diffractometer patterns show some weakening of the Ca-Mg ordering reflections relative to neighboring reflections, produced by the structural deviation necessary to accommodate the excess Ca in dolomite. In addition, the *c*-axis reflections and those with a strong *c*-axis contribution, particularly the higher-order reflections, tend to be broad and diffuse, whereas the *a*-axis reflections are relatively sharp. Diffraction pictures from small single crystals of these dolomites show all reflections to be less sharp however than the reflections produced by cleavage fragments of equivalent size from large crystals of normal dolomite. The imperfection of these dolomites is not a result of small particle size, as some of the materials examined were in the form of rhombohedral crystals up to 0.2 mm in size.

These materials have compositional and structural features related to those of the synthetic proto-dolomites already described by the writers.

ULTRAMAFIC AND MAFIC ROCKS OF THE ZAMBALES RANGE, LUZON, PHILIPPINES

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The pre-Tertiary crystalline rocks of the Zambales Range, which underlie more than 3000 square kilometers of this area, include both ultramafic and gabbroic types. In the area studied the mafic and ultramafic rocks occur in alternating belts 7 to 15 kms wide. Both the ultramafic and gabbroic rocks are rythmically layered; they may be parts of one differentiated complex; many of their contacts are interlayered. The occurrence of gabbro inclusions in dunite, and an outcrop showing peridotite intruding and crosscutting layered gabbro, suggests the possibility of more than one magmatic period.

The dominant rock types of the ultramafic sequence are olivine-rich saxonite and dunite, and some layers of pyroxene-rich saxonite and pyroxenite in the western ultramafic belt. In the gabbroic sequence the dominant rock types are olivine gabbro and anorthositic troctolite and less abundant norite, gabbro, and anorthosite. In a section 3,000 feet thick immediately above the ultramafic sequence the plagioclase ranges from An_{74} to An_{77} and averages An_{75}. Augite is the only pyroxene present. The olivine has a forsterite content of 85 to 95 per cent.

The gabbroic rocks show some unusual structures that resemble unconformities and channels in sedimentary rocks. Contemporaneous folding and faulting are also evident.

The ultramafic rocks are everywhere at least partially serpentinized.

Dike rocks include olivine gabbro, troctolite, and mafic pegmatitic dikes genetically related to the ultramafic and gabbroic rocks. Swarms of later dioritic to gabbroic dikes are very abundant in the eastern part of the area but are absent over much of the western ultramafic belt.

LITHOLOGIC AND STRUCTURAL CONTROLS OF URANIUM DEPOSITION IN THE HULETT CREEK MINING AREA, CROOK COUNTY, WYOMING*

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Structure maps made from plane-table surveys at scales of 1:6000 and 1:600 show that at Hulett Creek, Wyoming, the uranium-mineralized areas are near the top of the Fall River Sandstone,

* Publication authorized by the Director, U. S. Geological Survey.

of Early Cretaceous age, and at the base or along the edges of a northwest-trending sandstone lens about 8000 feet long, 2000 feet wide, and 20 to 45 feet thick. Laboratory studies of specimens of ore-bearing and barren rocks from the lens show that the lens is very fine-grained to fine-grained sandstone near the top and becomes slightly coarser downward and is fine- to medium-grained sandstone at the bottom.

The uranium ore consists of sandstone impregnated with carnotite and tyuyamunite above the ground-water table and uraninite and coffinite below. The ore occurs above clay or shale seams near the base of the sandstone lens where the sand grains are coarsest and where carbonaceous material is common. The largest mineralized zone in the lens occurs on the downthrown side of a northeast-trending normal fault. A structure-contour map of the base of the sandstone lens shows that the ore is concentrated along the fault in a synclinal trough. This suggests that the impervious gouge in the fault blocked ground-water solutions long enough for the ore to be deposited.

GONIATITE ZONES IN THE CHAINMAN SHALE EQUIVALENTS (MISSISSIPPIAN), WESTERN UTAH

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Studies now in progress in the Confusion Range, Utah, by the U. S. Geological Survey have shown that four major goniatite zones are present in the Chainman Shale equivalents, which is about 1850 feet thick. Late Meramec and all of Chester time seems to be represented.

The lower *Goniatites* zone begins 15 feet below a persistent massive gray limestone marker bed and extends up to 70 feet above it. This limestone, 10 to 20 feet thick, is 220 feet above the base of the formation in a section at Skunk Spring. *Goniatites crenistria* Phillips, *G. choctawensis* Shumard, and species of *Girtyoceras*, *Entogonites*, and *Dimorphoceras* identical with and similar to Alaskan and Midcontinent forms occur in this zone.

The upper *Goniatites* zone, about 90 to 220 feet above the marker bed, contains *Goniatites cumminsi* (Hyatt), *G. granosus* Portlock, *Neoglyphioceras cloudi utahense* (Miller, Youngquist, and Nielsen), *N. subcirculare* (Miller), *Dimorphoceras humphreyi* Youngquist, and *Pronorites baconi* (Miller, Youngquist, and Nielsen). Four of these species occur in equivalent beds in Arkansas, Oklahoma, and Texas; one occurs in Alaska.

Elements of the lower *Eumorphoceras* zone have been found only in the Burbank hills, roughly 320 to 800 feet above the marker bed. Besides "*Cravenoceras*" cf. "*C.*" *barnettense* (Plummer and Scott), nautiloids and belemnoids characterize this zone.

The upper *Eumorphoceras* zone, 25 to 550 feet below the top of the formation, contains *Cravenoceras merriami* Youngquist, *C. hesperium* Miller and Furnish, *C.* cf. *C. friscoense* (Miller and Owen), *Eumorphoceras bisulcatum* Girty, (*s. l.*), *Dimorphoceras* sp., and *Pronorites* sp.

MIXED-LAYER EFFECTS IN THE RHOMBOHEDRAL CARBONATES

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Synthetic dolomites and CaMn carbonates synthesized at low temperatures, as well as naturally occurring Cretaceous and Tertiary dolomites, frequently have asymmetric *c*-axis reflections tailing off toward higher 2θ values in contrast to *a*-axis reflections which are essentially symmetrical. This phenomenon indicates the existence of a range of periodicities in the *c*-axis direction. In order to characterize these materials more extensively, the most general equation of Hendricks and Teller has been solved for the 2-layer case and programmed for the University of Illinois digital computer Illiac. The requirement that layers of carbonate ions alternate with cation layers in these carbonates makes it possible to consider the two-layer packets $Ca\text{-}CO_3$ and $Mg\text{-}CO_3$ as single layers and reduces

the problem to a two-layer case. Diffractometer profiles are compared with theoretical (006), (009), and (00.12) profiles computed for a series of models in which layer succession and the extent of solid solution in cation layers have been varied.

DISTINGUISHING THE MANSFIELD SANDSTONE FROM CHESTER SANDSTONES IN INDIANA*

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Distinguishing the Mansfield Sandstone (Lower Pennsylvanian) from Chester (Upper Mississippian) sandstones in Indiana is difficult (in the absence of an overlying datable limestone) because of similar histories and similar depositional environments.

Extensive reworking of the sands has resulted in the significant presence of only the most stable minerals—quartz, zircon, tourmaline, and rutile. The depositional environments were similar enough to allow the introduction of iron oxides and clay minerals, the production of secondary growths on quartz (causing similar degrees of rounding), and the authigenic growth of anatase and brookite from leucoxene. These processes in combination have caused the sandstones to resemble each other closely.

Differences that can distinguish the sandstones can be found, however. The minimum median size of the Mansfield is 0.16 mm, and the maximum median size of the Chester is 0.24 mm. The sorting coefficients of the Mansfield range from 1.2 to 1.5, while those of the Chester range from 1.3 to 1.6. The numerous sandstone samples whose median size does not fall in the area of overlap and those few with a sorting coefficient of 1.2 or 1.6 are thus distinguishable. Apatite is not found in the Mansfield but occurs, sparsely, in the Chester. Illite and muscovite are more abundant in the Mansfield than in the Chester, although kaolinite is the dominant clay mineral in both. These differences, however, are not absolute enough to separate the sandstones always.

MUSTANG HILL LACCOLITH, UVALDE COUNTY, TEXAS

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Mustang Hill is one of about 90 small intrusions in Cretaceous sediments paralleling the Balcones fault zone of central Texas. Igneous activity in the province extends from earliest Cenomanian to Maestrichtian and includes some extrusive rocks. Faulting probably overlaps this period but is mainly later.

The Mustang Hill intrusion, 1½ miles in diameter, is an analcitic basalt with 27 per cent olivine, resembling mafic members of alkaline basalt suites from Scotland and Australia. Presence of distinctively diopsidic clinopyroxene, with absence of orthopyroxene and pigeonite, is confirmed as characteristic of this nonorogenic magma type. Limestone flags (Eagle Ford Formation) in the concordant floor of the intrusion dip 3°–10° centripetally and have been locally crumpled by the basalt in small-scale *decollements* over more massive limestone. Broader folding is related to subsidence beneath and around the intrusion.

Field relations and geophysical findings justify the name laccolith for this quasi-concordant mass. A detailed gravity survey reveals an asymmetrical maximum over the intrusion with 2.2 milligals of Bouguer anomaly relief. The highest point on the anomaly is in the southwest portion of the exposed igneous rock, whence the anomaly drops off sharply to the southwest, but has a relatively gentle gradient change to the northeast. The general shape of the anomaly suggests that the high

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point is associated with an igneous feeder, and the gentle gradient to the northeast is probably associated with a tabular body tapering away from the feeder.

SIZE-FREQUENCY DISTRIBUTION OF DETRITAL SEDIMENTS BASED ON SIEVING AND PIPETTE SEDIMENTATION

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The frequency distribution of 6976 phi medians from different sediments is characterized by $\bar{x} = 3.339$, $s = 2.442$, $Sk = 0.0084$, $K = 2.2406$. The skewness is not significant, and the distribution is therefore symmetrical. The kurtosis is highly significant.

To evaluate the meaning of this leptokurtosis the expected normal curve with $\mu = 3.339$ and $\sigma = 2.442$ was constructed; kurtosis is then displayed as

(1) excess of observed over expected in the -2.0 to -7.0 phi (gravel), 1.0 to 4.0 phi (sand), and less than 8 phi (clay) ranges; these are the sediments generally studied by petrographers.

(2) deficiencies of observed compared with expected occur in the -2.0 to 1.0 phi (fine gravel to coarse sand), and in the 4.0 to 8.0 phi (silt) ranges; size, in these intervals, is difficult to measure by conventional techniques.

Since the distribution is symmetrical and deficiencies arise from lack of suitable techniques, and not from an absence of sediments in these size ranges, additional samples, without change in technique, are unlikely to add to our information on the population distribution but will accentuate the sampling bias or leptokurtosis.

It may be presumed, then, that the population size-frequency distribution of medians determined by sieving and pipette sedimentation is log (phi) normal with $\mu = 3.339$ and $\sigma = 2.442$. Medians of the majority of detrital sediments will occur between -3.99 and 10.66 phi, the 99 per cent confidence limits of this normal curve.

TWO GRANOPHYRE BODIES NEAR MT. KATAHDIN, MAINE*

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Two types of granophyre bodies near Mt. Katahdin in north-central Maine are magmatically related but of different origin. One granophyre mass caps the higher mountains formed of quartz monzonite, the Katahdin granite of Toppan (1932). This capping is several hundred feet thick and may once have been nearly continuous over the top of the batholith. The upper contact of the capping is eroded away, and the lower contact is gradational into typical light-gray biotite-quartz monzonite. West of Mt. Katahdin the other granophyre has been intruded as sills, 20 to 300 feet thick, into shales and subgraywackes of probable Early Devonian age. The contacts are sharp and show chilled margins. The sills are petrographically related to thick quartz latite flows and welded tuffs that lie stratigraphically 2000 to 3000 feet above them. Both the sills and the volcanic rocks are intruded by the batholith but are thought to be associated with it.

The granophyre capping is red and contains miarolitic cavities lined with epidote, microcline, tourmaline, and quartz. The granophyre of the sills is gray with calcite-filled cavities.

Field, petrographic, chemical, and spectrographic data suggest that the red granophyre is the result of recrystallization of typical hypidiomorphic-granular quartz monzonite by late emanations from the consolidating pluton. The gray granophyre was formed by primary, simultaneous crystallization of quartz and alkali feldspar from a magma. The only other known near-by igneous body is a small quartz diorite stock 7 miles to the south.

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* Publication authorized by the Director of the U. S. Geological Survey.

CORRELATION OF AIRBORNE RADIOACTIVITY AND AREAL GEOLOGY

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The correlation of airborne radioactivity data and areal geology in several areas of the United States is being investigated by the U. S. Geological Survey. A study of radioactivity profiles, obtained by using equipment and surveying techniques developed in the search for deposits of radioactive minerals, indicates that airborne radioactivity surveying can materially assist the field geologist by determining continuity between outcrops. In an area of Triassic rocks near Bealeton, Virginia, it is possible to differentiate between diabase and shale on the basis of their radioactivity values, and an areal geologic map can be prepared from the data. Distinctive airborne radioactivity units in Marquette County, Michigan, can be correlated with sedimentary rocks of Cambrian age and an area of Precambrian granite near Republic, but the areal geology of the entire area is not adequately portrayed by the radioactivity units. Airborne radioactivity surveying is of definite value in areas of low relief and residual soil such as the Piedmont, but it has limitations in areas of moderate relief or where the surficial material is not residual soil. Present investigations include study directed toward determining whether changes in surveying technique or modifications in equipment will produce data of more use from the standpoint of areal geology.

FIRST SUMMER INSTITUTE IN GEOLOGY, 1957

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Twenty-six teachers of geology from colleges throughout the country met at the Department of Geology, University of Illinois, from June 17 to August 10 to participate in the Institute in Geology. This program of study and research was sponsored by the National Science Foundation and was conducted by D. M. Henderson, A. F. Hagner, and R. M. Garrels. Fulfillment of the program was aided by the staff and resources of the University of Illinois and the State Geological Survey.

The first 4 weeks was devoted to obtaining a background in the geochemistry of common hydrous systems under atmospheric conditions and the principles of atomic construction of minerals and their control of geologic behavior. In the laboratory, participants were introduced to the use of pH-Eh measurements, x-ray diffraction, electron microscopy, and x-ray spectrography.

The second 4 weeks was devoted to lectures by 12 visiting geologists and to research by the participants. The lecturers discussed examples of experimental, nuclear, theoretical, statistical, and field approaches to the solution of geologic problems.

The impact of these approaches and techniques on geologic education was discussed in informal sessions. Participants felt that institutes of this type are an effective means of: (1) stimulating new outlooks on geologic research, (2) encouraging new directions in teaching, (3) providing an opportunity for acquiring and synthesizing recent contributions to geology, (4) providing for a close association and exchange of ideas with teachers facing similar problems, (5) carrying on independent research with modern equipment, and (6) associating informally with outstanding contributors to geology and discussing problems of mutual interest.

CHEMICAL AND PHYSICAL PROPERTIES OF CHLORITOID

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The chemical composition, X-ray, and optical properties of chloritoids from more than 30 localities have been studied. Five new chemical analyses of chloritoid (including one so-called ottrelite from

Salm Château, Belgium) and all the previously available analyses which were deemed satisfactory indicate that its formula may be written as $FeAl_2SiO_5(OH)_2$. Two-fifths of the Fe″ may be replaced by Mg, and less than one-fifth by Mn.

Chloritoid crystallizes in two polymorphs with the following C-centered unit cells.

	a	b	c	α	β	γ
Monoclinic (Natic, Rhode Island)	9.48A	5.49	18.19	90° 0′	101° 55′	90° 0′
Triclinic (Chibougamau, Quebec)	9.50	5.48	9.16	96° 53′	101° 49′	90° 2′

This triclinic unit cell can be geometrically related to the structure of monoclinic chloritoid determined by Harrison and Brindley by a zig-zag arrangement with approximate doubling of c. Chloritoids from hydrothermal environments are commonly triclinic. Both polymorphs occur in metamorphic terrains, but the monoclinic polymorph is more commonly associated with almandine.

The refractive indices of chloritoid decrease with increasing magnesium content: α lies in the range 1.713 to 1.730, β 1.719 to 1.734, and γ 1.723 to 1.740. In 11 samples $2V_x$ ranges from 36° to 125° but is mostly 45° to 60°. $Z \wedge (001) = 60°$ to 88°. $X = b$ in monoclinic chloritoid. X and Y make angles from 0° to 30° with (001) in triclinic chloritoid. Because of these variations caution is required in the use of optical methods to distinguish the polymorphs.

SYSTEM MgO-CO_2-ARGON, AND THE EFFECT OF INERT PRESSURE ON CERTAIN TYPES OF HYDROTHERMAL REACTION

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The effect of inert pressure on the equilibrium thermal dissociation of magnesite ($MgCO_3 \rightleftharpoons MgO + CO_2$) has been determined between CO_2 pressures of approximately 10,000 and 20,000 pounds per square inch. Modifications of the conventional hydrothermal equipment and techniques are necessary in this type of study to insure homogeneity in the polycomponent fluid phase throughout the experiments. It has been proved that without such modifications completely misleading results are produced. The univariant P-T curve for the above reaction is displaced to lower temperatures as the argon:CO_2 ratio is increased. The relationship is such that, if the composition of the fluid phase is known, then the temperature of dissociation, T, at a fixed total pressure, P, can be estimated from the already known P_{CO_2}-T data. Within the limits of experimental error and within the P-T range examined, $T = f\{Pw\}$, where w = weight per cent of CO_2 in the fluid phase.

It is anticipated that in regions of a single metamorphic zone somewhat higher-grade mineral assemblages may appear in carbonate-hydrate rocks than in the more purely carbonate or purely hydrate members.

REPLACEMENT GNEISSES IN THE GARDNER LAKE AREA, WYOMING

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Individual areas in the Gardner Lake area, Wyoming, are being mapped on a scale of 1 inch equals 500 feet, to form a strip across the granitic core and migmatite mantle of the Beartooth Mountains, Montana-Wyoming. Bedding foliation, compositional banding, and rock units indicate open, southward-plunging folds traceable through the migmatites into granitic gneisses. The direction of axial-plane foliation in highly contorted metasediments is found locally within the foliation

trends of the gneisses. Gradation of rock types from amphibolite to pink leucocratic gneiss is indicated by distribution of mapping units, abundance and composition of feldspars and ferromagnesian minerals, percentage and character of rounding, overgrowths, and length-width ratios of zircons, and variations in bulk chemical analyses. Mafic intrusives are pre-, pene-, and post-granitization, and their trends suggest that Laramide uplift and faulting are controlled by structural elements developed during the cycle of metamorphism and feldspathization. Seven K-A and Rb-Sr ages on micas and feldspars from different gneisses and pegmatites indicate that this cycle is 2.7 billion years old. Temperatures of 445° C.–480° C. for the pegmatites are calculated on the basis of Na content of muscovite.

COMPARISON OF METHODS OF PETROGRAPHIC ANALYSIS AND THEIR RELATION TO THE COKING CHARACTER OF COAL

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Various methods of analysis have been used in determining the petrographic composition of coal in fundamental and applied studies. The relative merits of three methods are compared.

Analysis of 30 samples by three methods of analysis—the integrating-stage, point-count, and oriented-sample methods—showed generally comparable quantitative results although the integrating-stage and oriented-sample results were in much closer agreement than were those obtained by the point-count method. The oriented-sample method was used in a recent laboratory coking investigation at the Illinois Geological Survey and provided information on the size and distribution of macerals.

A rapid method of evaluating petrographic composition qualitatively (*i.e.*, "fabric" or size and relationship between the macerals) is needed. The oriented-sample method provides a qualitative evaluation but is of limited value because the analysis is time consuming. Both the integrating-stage and point-count methods are relatively rapid but provide only a quantitative evaluation. The qualitative information is of concern in evaluating coal for utilization, particularly as related to improvement of the character of the coke.

THICKNESSES OF MARGINAL ZONES OF VANISHED GLACIER ESTIMATED FROM THE PRECONSOLIDATION-PRESSURE VALUES OF OVERRIDDEN SILTS*

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Thickness values for vanished glaciers are useful in solving many difficult problems in glacial stratigraphy, sedimentation, and geomorphology. Values of the preconsolidation pressures of silts overridden by four Wisconsin stage ice advances were determined in the soil-mechanics laboratory at Purdue University. From the results of seven consolidation tests part of the vanished East-White sublobe of central Indiana was reconstructed. The paleoglacier map that is presented for this sublobe is for the particular advance whose maximum extent is delineated by the "Champaign" drift boundary. The map shows altitudes on the vanished glacier surface and 200-foot contours as much as 25 miles back from the margin. The glacier is determined to have been 1690 feet thick at a point 27.6 miles from the margin.

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A log-log plot of glacier thickness (in feet) at a consolidation-test site versus the thickness (in feet) of the till deposited by the glacier yields a linear relationship, fitted by the power function $y = 3.15x^{1.00}$. A log-log plot of the distance (in miles) of a sample site from the glacier margin versus the till-sheet thickness (in feet) at the sample site yields an approximately linear relationship, $y = 0.02x^{1.8}$.

The first power function may represent a rough erosion-transportation rule for the vanished "Champaign" glacier—*i.e.*, the thickness of material (in feet) which the glacier eroded and transported was approximately equal to 0.32 (the glacier thickness [in feet])$^{0.59}$.

1908 MESSINA EARTHQUAKE, TSUNAMI, AND TURBIDITY CURRENT

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At (0520) December 28, 1908, the Straits of Messina suffered a severe earthquake (magnitude 7.5) which destroyed the city of Messina and near-by communities. Of the seven submarine cables which linked Italy and Sicily within the area of maximum intensity ($> X$) only two were damaged. Ten hours (1515 hrs.) after the quake the Malta Zante Cable failed 120 miles to the south in 1800 fathoms depth, requiring the replacement of 45 miles of cable. The explanation is the same as that previously offered for the similar 1929 Grand Banks and 1954 Orleansville occurrences. The earthquake generated a slump which continued as a turbidity current and broke the successive cables. The average velocity of the 1908 Messina Turbidity Current was 12 knots. The cables lying in the shallower parts of the straits, although directly within the epicentral area, did not break because the strong tidal currents of the strait had transported all unconsolidated sediments to the ends of the strait. The strong tsunami which swept repeatedly in against the surrounding coasts was probably generated by the turbidity current.

The Straits of Messina are considered to be a production center of turbidity currents. Sediment from the shore, captured by eddies and strong tidal currents, is sorted and swept into intermediate depths, where it is temporarily deposited until earthquake-triggered slumps and turbidity currents ultimately carry the sediment into deep water. This illustrates an important means of dispersal which must have played an important role through geologic time.

EXTENDING THE LIMITS OF THE CONGO SUBMARINE CANYON

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In May 1957 the Research Vessel VEMA made a brief survey of the Congo submarine canyon. The canyon was found near the seaward limit of the earlier surveys and extended 150 miles to the west where it reaches depths of 2200 fathoms. At the 550-fathom contour the canyon is about 5 miles wide at its top and 500 fathoms deep with abrupt walls and a V-shaped bottom. This acute V-shaped appearance characterizes the canyon out to the 2000-fathom contour. Four biological trawls and seven sediment cores were collected from the canyon walls and floor. One trawl in 2140 fathoms contained abundant tree leaves and a rich fauna. The canyon floor cores contained sand and organic debris.

The Congo canyon was first discovered by cable-repair ships; the canyon was very frequently the site of cable failures. The repeated failure of cables crossing the canyon as well as the occurrence of tree leaves and beds of detrital sediment in the canyon floor can be adequately explained by repeated turbidity currents originating in the river estuary and flowing down the canyon to the Angola abyssal plain. In contrast to the other large rivers the Congo is not building a delta. Virtually

its entire load is being carried by turbidity current to the floor of the Angola basin via the Congo submarine canyon.

BROWN DERBY PEGMATITES, COLORADO. I: COLUMBITE AND STIBIOTANTALITE

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Columbite occurs in the Brown Derby No. 2 pegmatite, Gunnison County, Colorado, chiefly as subhedral tablets ($G = 5.613$) up to several inches long, in a lens of albite, quartz, schorl, zinnwaldite, garnet, and euhedral monazite between the quartz core and the hanging wall. In the Brown Derby No. 1, larger pods and tablets of columbite ($G = 5.632$) occur in wall-zone rock in red sodic plagioclase, and intergrown with and replaced by euxenites. Columbite and euxenite locally include minute specks of galena. In polished section, both columbites show subordinate alteration to a darker-gray, moderately anisotropic phase. The columbites are not radioactive; they produce no autoradiographs even after exposure for 30 days. Euxenite is metamict, homogeneous to markedly variable in reflectivity.

Stibiotantalite, first found in 1953, occurs in the Brown Derby No. 1 as irregular steel-gray pods, with a resinous luster, up to several inches long intergrown with pink tourmaline in albite-lepidolite pegmatite. Analysis indicates about 40 per cent Ta_2O_5; but G = 6.20–7.34, indicating a considerable variation in the Ta:Nb ratio. Bismuth is absent. Veinlets of quartz and a colorless mica with 2V = 0° (phengite) transect the stibiotantalite anhedra.

RE-EXAMINATION OF RHABDOPHANE (SCOVILLITE) FROM SALISBURY, CONNECTICUT

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U. S. Geological Survey, Washington 25, D. C.

Rhabdophane, a hydrous cerium-earth orthophosphate, is found only at Cornwall, England, and Salisbury, Connecticut. At Salisbury it occurs as tan botryoidal incrustations in the brecciated Scoville iron-ore bed, in association and contemporaneous in origin with lithiophorite, goethite, a serpentinelike mineral (bementite?), and halloysite. The type rhabdophane (Cornwall; origin uncertain) is described as small, brown translucent globules easily mistaken for sphalerite. Lettsom (1882) reported Ce_2O_3 23.19, Y_2O_3 2.09, and $(La,Di)_2O_3$ 34.77 per cent and the formula $(Ce,Di,La,Y)PO_4 \cdot H_2O$.

Rhabdophane from Salisbury, reanalyzed, has the following percentage composition, in remarkable agreement with Brush and Penfield (1883): La_2O_3 18.9, CeO_2 0.5, Pr_6O_{11} 0.5, Nd_2O_3 26.6, Sm_2O_3 4.5, Eu_2O_3 0.9, Gd_2O_3 4.4, Tb_4O_7 0.4, Dy_2O_3 0.6, Ho_2O_3 0.3, Y_2O_3 8.9, Er_2O_3 1.1, Tm_2O_3 0.2, Yb_2O_3 0.9, Lu_2O_3 0.2, P_2O_5 23.1, CO_2 3.2, H_2O^+ 5.9, H_2O^- 1.1, F 0.3, total 102.5. Its chemical formula is $(RE)_{1.0}[(PO_4)_{0.8}(CO_3)_{0.1}(OH,F)_{0.1}] \cdot 0.9\ H_2O$. X-ray and differential-thermal analysis studies indicate that the CO_2 is an inherent part of the structure as in carbonate apatite, and that a lanthanite admixture suggested by Brush and Penfield is nonexistent. This rhabdophane contains unusually low percentages of CeO_2 and Pr_6O_{11} and high percentages of $(La,Nd,Y)_2O_3$, not ordinarily observed in rare-earth minerals. The principal interplanar spacings *d* (A) are 3.00, 2.81, 5.99, 4.36, 3.46, 2.14, and 1.85.

This study shows that rhabdophane is isostructural with bassanite and with synthetic hydrous

cerium phosphate (hexagonal modification), but large percentages of cations with smaller ionic radii than cerium make its unit-cell size appreciably smaller than the synthetic isotype.

SILICA STRUCTURE STUDIES. V: TRIDYMITES

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Tridymite has been synthesized using purity samples of quartz, cristobalite, silica glass, silica gel, and silicon metal as starting material, and H_2O, D_2O, H_2O-HF, H_2O-NaOH, and Na_2WO_4 as fluxes. Various temperatures and pressures within the stability field of tridymite were used. In all cases the reaction path was found to be: Starting material → Cristobalite (disordered) → Tridymite.

Two distinct polymorphs of tridymite, related by a reconstructive transformation, have been identified. These have unique X-ray-powder patterns and DTA patterns which can be used to identify them either in their pure form or in mixtures. Their inversion temperatures are:

Tridymite-S: sharp inversion at 110–115°C, and weaker inversion at 165°C

Tridymite-MS: sharp inversion at 110–120°C, and diffused inversion at 140–150°C.

Tridymite-MS appears to be metastable with respect to tridymite-S.

There is also some indication for the existence of disordered forms of tridymite.

High-purity tridymite from transistor-grade silicon and D_2O was made in a sealed gold capsule at 932°C. and 4,000 psi; it had no weight loss or change in diffraction pattern after heating at 1300°C for 48 hours, and the infra-red pattern did not show any absorption in the 3–5μ region. Tridymite with Na ions in "solid solution" prepared from Na_2WO_4 fluxes shows definite shifts in X-ray spacings. Similar forms were also identified in silica bricks.

The data confirm tridymite as a stable polymorph of SiO_2.

THERMOCHEMICAL DATA, MINERAL ASSOCIATIONS, AND THE LINDGREN CLASSIFICATION OF ORE DEPOSITS

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Thermochemical data on compounds of many of the metals of interest in problems of ore deposition have been compiled during the last few years. These data have been used to construct diagrams defining the stability fields of 19 native metals and their oxides, sulfides, sulfates, and carbonates. The stability fields of all but the carbonates are represented in three-dimensional diagrams of which the axes are the fugacity of oxygen, the fugacity of sulfur, and the temperature. The carbonates are represented by replacing the temperature axis by a CO_2-fugacity axis and by constructing a series of isothermal S_2-O_2-CO_2 diagrams.

Mineral assemblages commonly found in metallic ore deposits occupy well-defined volumes in these diagrams. This indicates that ore deposition normally takes place at or near equilibrium, and that such diagrams can be used to define approximately the fugacity of sulfur, oxygen, and carbon dioxide at the time of ore deposition.

The fugacity of sulfur and that of oxygen increase smoothly with temperature, proceeding from Lindgren's epithermal, through the mesothermal, to the hypothermal group of deposits. The shift in the S_2 and O_2 fugacities with temperature can be interpreted quantitatively in terms of the cooling of mixtures of gases consisting largely of H_2O, CO_2, and H_2S. The proposed manner of representation thus leads to a theoretical basis for the study of mineral associations in metallic ore deposits, for the Lindgren classification, and for some of the classical ideas on the composition of ore forming fluids.

SIGMOIDAL DUNES: A TRANSITIONAL FORM

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A sigmoidal dune is an S-shaped, steep-sided, sharp-crested dune formed under the influence of alternating and opposing winds of roughly equivalent velocities. Slopes range from 10° to about 24° except in temporary slip faces which are 30°–33°. Steep slopes and sharp crests are characteristic of active sigmoidal dunes. Rounded slopes and convex upper surfaces develop in periods of low-velocity winds from varying directions, frequently upon dunes of low relief. Dimensions vary with wind intensity and abundance of sand but conform with size of other dunes in the region, usually up to 50 m high, 1–2 km long, and 50–200 m wide.

The sigmoidal dune is transitional between the crescentic dune and some of the dune complexes, such as the pyramidal, the wedge-shaped massifs, the anastomosing linear complexes, and the linear belts with V-shaped chevrons that center in an axis of elongation. It stands best developed in regions where the wind regime drives sand from opposite directions in alternating periods, under roughly equivalent velocities. If the wind regime suffers an imbalance, the sigmoidal dune may dissolve into one of the crescentic dune forms or combine with adjacent dunes to form one of several possible dune complexes. The pyramidal dune forms from two or more sigmoidal dunes under wind regimes that shift continually around the compass.

SAND PAVEMENTS IN THE RUB' AL KHALI

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Sand pavements, akin to desert pavements but in sand-grain size, are deflation phenomena developed during periods of intermittent, light, variable winds. These pavements, derived from coarse-grained sand ripples, are formed of large sand grains with a narrow range of grain size, so closely spaced and juxtaposed as to form a smooth, continuous surface of sand about one grain in thickness and ranging upward in area from a few yards square.

Mirrorlike, they reflect light but impart a darker color to the surfaces on which they form; once formed they are resistant to wind and become indicators which record in sand deposits the occurrence of certain atmospheric conditions. Environmentally, they develop on the lower slopes of the windward side of sand masses and are distributed on the surfaces of rolling sand areas and dune slopes.

SPACE GROUPS, PLANE GROUPS, AND TWIN SYMMETRY

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The two-dimensional discontinuity at a twin boundary is bridged by a slice of structure shared by both crystals. The possible twin-symmetry operations derive logically from this single structural condition.

The sharing of boundary structure allows relations by any symmetry operation that is present in the boundary structure but not in the crystal structure. A slice of crystal structure when considered alone may have symmetry elements in its plane pattern that are not in a corresponding plane section of the crystal's space group. Such a slice is a possible boundary structure, and the extra elements of symmetry are possible twin operations. However, the extra symmetry must be compatible with the sectional plane group, so that the sectional plane group is a subgroup of the boundary-plane group (it is also a subgroup, in the general sense, of the crystal space group.) The possible twin symmetry

operations are thus limited by these relations with the crystal space group and the position of the boundary.

The plane groups are two-sided and number 80. In these groups there are 14 types of symmetry operation differing with respect to the plane, which reduce to 11 twin-point symmetries, and to 5 if the crystal is centric. Three-fold, four-fold, or six-fold twin axes are as acceptable as two-fold, although only perpendicular to the plane. Also two-fold axes parallel to the plane lie at 90° (or 120°) to one another in some plane groups, although one of these directions may be irrational in the crystal.

ORIGIN OF LAMPROPHYRES ASSOCIATED WITH THE CHELAN BATHOLITH, WASHINGTON

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A dike series, ranging from basic barkevikite-plagioclase lamprophyre to acidic microquartz diorite, cuts the margin of the Chelan batholith and its wall rocks. The following evidence indicates that the lamprophyre dikes were injected as quartz diorite magma from the Chelan batholith, then were desilicated and changed to lamprophyre during crystallization: (1) Chilled lamprophyre dike margins are more acidic than are the dike interiors, and preserve a relict quartz diorite mineral assemblage. (2) Distinctive hornblende and zoned plagioclase of the Chelan batholith quartz diorite occur also in the dike rocks. No basic lamprophyre source rock for the dikes is exposed in the region.

Morey's vapor-transport experiments, showing that much silica may be leached from quartz and other silicates by supercritical water at high pressures, suggest the following possible desilication mechanism for the Chelan dikes: Newly injected, crystallizing acidic dikes, serving as escape channels for highly compressed hydrous fluid in the magma chamber, might be desilicated to lamprophyre by leaching action of the escaping silica-undersaturated fluid. Such desilication would probably be possible only a great distance up the dike from the magma chamber, where the ascending fluid became silica-undersaturated, perhaps by passing through a *P-T* region of retrograde silica solubility and/or by losing CO_2 through carbonate formation. Thus the lamprophyres should grade downward into more acidic dikes. Intermediate members of the dike series may represent incompletely desilicated dikes.

Secondary barkevikite, chlorite, apatite, and carbonate were probably formed by reaction of the escaping fluid with primary dike minerals.

PRELIMINARY EXPERIMENTS ON THE TRANSPORT OF SILICA IN WATER AT HIGH TEMPERATURES AND PRESSURES

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Laboratory experiments show that relatively large amounts of silica can be transported in supercritical water. Moreover, they strongly suggest that the movement of the fluid is not essential to the transport of silica, but that the dissolved silica diffuses readily through the fluid in response to a concentration gradient.

Under hydrothermal conditions (up to 700°C. and 23,000 psi. H_2O) dissolved quartz diffuses through small orifices at rates generally greater than 6 milligrams/cm²/hour. When the diffused silica reacts with brucite flakes at 585°C. and 15,000 psi., a transport rate of 46 milligrams SiO_2/cm.²/hour has been measured. When the diffused silica reacts with calcite grains, thereby producing carbonated water, transport rates as high as 200 milligrams SiO_2/cm.²/hour have been obtained.

It is expected that higher transport rates will be obtained with steeper concentration gradients. The concentration gradients in the experiments mentioned above were limited by the rate of solu-

tion of quartz and the rate of removal of silica from solution by its reaction with calcite or brucite, or by its precipitation in the cooler parts of the autoclave.

ORIGIN OF SILLIMANITE ROCKS BY ALUMINA METASOMATISM, WICHITA MOUNTAINS, OKLAHOMA

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Field investigations during 1950–1954 have clarified the petrogenesis of the Precambrian gabbro-granophyre complex and the occurrence of sillimanite-bearing rocks of the Wichita Mountains in southwestern Oklahoma.

Field occurrences and petrographic studies indicate that the transformation of quartzite and igneous rocks of various composition into rocks rich in sillimanite and related minerals was a result of metasomatic process in which Al_2O_3-rich fluids play an important part. The sillimanite rocks studied represent areas where solutions of Ca, Mg, Fe, etc., in the pre-existing rocks accompanied precipitation of the aluminum silicate. The Al_2O_3 necessary for the metasomatism is derived from the granophyric melt. Barth's rock-standard cell is used in the discussion of the metasomatism.

At the focal point of metasomatic replacement the rocks consist essentially of sillimanite with subordinate plagioclase, orthoclase, quartz, corundum, sphene, chlorite, prehnite, muscovite, and clinozoisite. Epidote is widespread. Action of water upon gabbroic rocks during the metasomatism at low temperature may have assisted its formation.

The appearance and disappearance of active elements during the metasomatic process is significant. SiO_2 and TiO_2 were active throughout the entire metasomatic process. The order for the other ions is Al, Fe^{III}, Mg, Fe^{II}, Na, K, and OH. Ions of increasing radii enter into the reaction as the processes of metasomatism progress. (The radii of the ions just listed in Å units are: Si 0.39, Al 0.57, Ti 0.64, Fe^{III} 0.67, Mg 0.78, Fe^{II} 0.83, Na 0.98, K 1.33 and OH 1.33.)

ROLE OF FLUID PRESSURE IN MECHANICS OF OVERTHRUST FAULTING

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Promise of resolving the overthrust-faulting paradox arises from a consideration of the influence of the pressure of interstitial fluids upon the effective stresses in rocks. If, in a porous rock filled with a fluid at pressure p, the normal and shear components of total stress across any given plane are S and T, then

$$\sigma = S - p, \tag{1}$$

$$\tau = T \tag{2}$$

are the corresponding components of the *effective* stress in the solid alone.

According to the Mohr-Coulomb law, slippage along any internal plane in the rock should occur when the shear stress along that plane reaches the critical value

$$\tau_{crit} = \tau_0 + \sigma \tan \phi; \tag{3}$$

but once a fracture is started τ_0 is eliminated, and further slippage results when

$$\tau_{crit} = \sigma \tan \phi = (S - p) \tan \phi. \tag{4}$$

From this it follows that, without altering $\tan \phi$, the coefficient of friction, the critical value of the

shear stress can be made arbitrarily small simply by increasing the fluid pressure p. In a horizontal fault block the total weight per unit area, S_z, of the overburden is jointly supported by the solid stress σ_z and the pressure p; and as p is increased σ_z is correspondingly diminished until, when $p = S_z$, $\sigma_z = 0$.

Hence, given sufficiently high fluid pressures, very much longer fault blocks could be pushed over a nearly horizontal surface than otherwise would be possible. That the requisite pressures actually do exist is attested by the increasing frequency with which pressures approximating $0.9S_z$ are being observed in deep oil wells in various parts of the world.

STRATIGRAPHIC CORRELATION USING SPECTROCHEMICAL ANALYSES

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Spectrochemical analyses of 373 Silurian samples obtained from 16 standard-drilled wells in the Michigan basin were made. Analyses were done with a quartz prism, Littrow-type instrument. An exposure of 60 seconds with an a.c. arc was used on powdered samples mixed with cupric oxide and graphite. SiO_2, Fe_2O_3, Al_2O_3, MgO, and CaO were determined with a reproducibility of ± 10 per cent. All analyses were made in duplicate.

Using the spectrochemical data in conjunction with sequence of strata it was found that the Clinton Formation can be recognized. Furthermore, it was found that the Lockport Dolomite can be subdivided into three units. The A Unit at the base is characterized by its extreme purity, the B Unit by two characteristic strata with silica values of approximately 1.2 per cent, and the C Unit by its comparatively high silica, iron, and alumina. These spectrochemically determined units can be braced from well to well and show regional variations in composition.

THIN-SECTION PETROLOGY OF THE LOWER KINKAID LIMESTONE, UPPER MISSISSIPPIAN, ILLINOIS AND KENTUCKY

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The Kinkaid Formation (Chester Series, Mississippian) outcrops and underlies Pennsylvanian rocks in southern Illinois, southern Indiana, and western Kentucky. It commonly consists of two massive limestones each averaging 20 feet thick, separated by about 100 feet of shale. The lower limestone was sampled at seven localities along 125 miles of its outcrop. The sampling interval was 1 foot.

From a series of thin sections for each locality it is possible to classify the textures and principal organisms and to make tentative interpretations of changes in conditions of sedimentation during the accumulation of the limestone at a single locality and to note progressive changes in texture and faunal content in a particular zone of the limestone along its outcrop.

The limestone generally has a zone with abundant thin-shelled gastropods and small algal colonies near its base. Higher in succession there are zones (1) with abundant Foraminifera, (2) with well-preserved brachiopods, especially productids, and (3) with broken and abraded crinoid stems and Bryozoa. In extreme southern Illinois the lower part of the shale above the Lower Kinkaid Limestone changes to a limestone facies displaying thin varvelike laminae, graded bedding, slump structures, and in some beds abundant sponge spicules. This limestone is believed to have accumulated in deeper water than the normal Lower Kinkaid Limestone.

HYDROGEOCHEMICAL EXPLORATION FOR URANIUM IN THE MT. SPOKANE AREA, WASHINGTON

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The applicability of the hydrogeochemical method of uranium exploration in eastern Washington has been tested. The geochemistry of the waters and the rock environment associated with the waters were considered. Chemically the waters are of the carbonate type and divided into three groups according to the amount of total dissolved material. These three groups correspond to an arbitrarily selected grouping of geologic environments: (1) intensely decomposed granitic rock; (2) fresh granitic rock; and (3) sedimentary lake-bed deposits overlain by Columbia River lavas.

The areal-background analysis for uranium in surface waters was determined to be approximately 1.5 parts per billion as compared with the regional background of 0.2 parts per billion. The area background for spring waters was found to be about 4.5 parts per billion. Several springs in the area are radioactive and can be easily detected with a hand scintillation counter. Anomalies in the amount of 100 ppb were detected.

Comparisons of uranium with the pH and bicarbonate content of surface waters showed that uranium occurs in anomalous concentrations only where the bicarbonate content is greater than 25 parts per million and the pH is greater than 6.5.

Limitations of the hydrogeochemical method in the Mt. Spokane area are similar to those encountered elsewhere. Not all waters with abnormally high uranium indicate the presence of uranium ore deposits. The major factor of distance between an ore deposit and the surface openings of adjacent springs needs further evaluation. Other significant limitations are the presence of intermittent and discontinuous surface drainage, and variations that may occur in the composition of waters caused by climatic changes.

NORMATIVE ANALYSIS OF FINE-GRAINED SEDIMENTARY ROCKS

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Bulk chemical analyses of more than 100 samples of limestone, argillaceous limestone, calcareous shale, argillaceous dolomite, and related rock types from the Florena Shale (Permian, Kansas) have been recalculated in terms of mineral composition. Set up as routine operation on a mimeographed form, the method of calculation outlined here requires less than an hour to perform and check. Although certain simplifications and assumptions are involved, the calculation provides a reasonably accurate statement of the proportions of free silica, calcite, dolomite, and total clay, and identifies the predominant clay-mineral group.

Major minerals in the Florena are calcite, dolomite, chert, illite, and montmorillonite; chief accessories are pyrite, albite, hematite, and sericite. In addition to these minerals, gypsum, apatite, and sepiolite are assumed to be present for purposes of the modal analysis. The following simplified chemical formulae are adopted: illite, $2K_2O \cdot 3MgO \cdot (Al_2O_3, Fe_2O_3)_8 \cdot 24SiO_2 \cdot 12H_2O$; montmorillonite, $(Al_2O_3 \cdot Fe_2O_3)_2 \cdot 8SiO_2 \cdot 2H_2O$; sepiolite, $2MgO \cdot 3SiO_2 \cdot 4H_2O$.

After restating the bulk analysis in terms of molecular ratios, TiO_2, Na_2O, P_2O_5, SO_3, and S are disposed of as sphene, albite, apatite, gypsum, and pyrite. Next, all the CaO and CO_2, and as much MgO as is required, are used to form calcite and dolomite. The balance of the MgO and all the K_2O are then used to form illite and either sericite or sepiolite depending on the relative amounts of MgO and K_2O. Finally, the unused sesquioxides are computed as montmorillonite, and the residual SiO_2 is regarded as chert.

PHASE TRANSITIONS IN SODIUM TUNGSTEN BRONZE

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A temperature range over which a twinned structure exists has been found for single crystals of sodium tungsten bronze, Na_xWO_3, for x greater than 0.5. Both the upper and lower temperature limits of this phase vary as a function of the sodium content. The twinned phase is birefringent, and its optical behavior can be described in terms of a tetragonal cell with c/a slightly less than 1. The untwinned phase is not birefringent. The transformation at both temperatures is comparable to the cubic-tetragonal inversion in $BaTiO_3$ at 120°C.

ENGINEERING GEOLOGY OF GLEN CANYON DAM SITE, COLORADO RIVER, ARIZONA

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The Glen Canyon Dam and Powerplant, now under construction, is located in northern Arizona in a canyon section of the Colorado River. The dam will be a concrete arch-type structure with crest length 1580 feet and height about 700 feet above bedrock. Foundation and abutments consist wholly of Jurassic Navajo sandstone. At the dam site the formation is more than 1300 feet thick, essentially horizontal, free from major structural defects, and characterized by widely spaced, near-vertical joints generally parallel and normal to the river axis. The sandstone ranges from soft to moderately hard and is massive with pronounced cross-bedding. It is composed principally of quartz and minor amounts of feldspar grains variably cemented primarily with secondary quartz, minor amounts of hematite, and some chalcedony and calcite.

Field and laboratory investigations for design data included geologic mapping, drill holes, drifts, geophysical and other special testing to define site conditions, petrographic, and engineering properties of the sandstone. Foundation drill holes were supplemented by vertical and angle holes in both abutments. The angle holes were drilled approximately parallel to the resultant thrusts of the dam at selected elevations in order to assure proper evaluation of the elastic properties of the rock along thrust lines.

Engineering and geologic data secured in the extensive testing programs, bearing on unconfined and triaxial compressive strength, modulus of elasticity, permeability, porosity, and other properties of the sandstone and its behavior, will be outlined and discussed with relation to design problems.

PRELIMINARY RESULTS FROM EXPERIMENTAL MELTING AND CRYSTALLIZATION OF HARDING, NEW MEXICO, PEGMATITE

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Samples of finely ground natural pegmatite, representing the mineralogically complex main Harding dike in Taos County, New Mexico, were fused in Tuttle cold-seal bombs at temperatures of 800°–900°C. and under water-vapor pressures of 20,000–25,000 psi. The charges were allowed to crystallize over a falling temperature gradient at essentially constant pressure, and most were quenched before complete crystallization. The synthetic pegmatite bodies thus obtained duplicate in miniature, most of the mineralogical, textural, and structural features characteristic of natural occurrences, including many features regarded as peculiar to pegmatites.

Preliminary results of the experimental work also indicate that: (a) under moderate water-vapor

pressures, Harding pegmatite is completely liquid at 650°C. and is partly liquid below 550°C., suggesting that constituents other than water must be effective in lowering the liquidus region of some natural pegmatitic melts; (b) transfer of material by diffusion through a gas phase can be very important in pegmatite crystallization, and the possibility of resurgent boiling in natural pegmatite systems merits serious consideration; and (c) experimental work with natural materials and comparison of its results with data obtained from purely synthetic systems offer much promise in the study of pegmatite genesis.

METHOD FOR ESTIMATING COST OF TUNNELS

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The California Water Plan envisions the construction of hundreds of miles of aqueduct extending from the Oregon boundary to the Mexican border. To determine the most feasible routes, the costs of a large number of possible alignments must be compared. A method has been designed whereby preliminary cost estimates of the tunnels involved are obtainable from geologic information. Compilation of this method has involved the review of construction histories for 120 modern tunnel projects, inspection of tunnels under construction, interview of contractors, and the retention of a tunnel consultant. From data thus obtained, geologic conditions were related to rate of heading advance overbreak, and tunnel-support requirements.

The costs per day for driving tunnels ranging from 9 to 30 feet in diameter were next estimated from an analysis of the labor, equipment, and material requirements at many projects. Using the estimated rates of heading advance and the daily costs for tunnel driving, curves were compiled relating excavation cost to tunnel diameter for each of nine possible physical rock conditions ranging from intact rock to completely crushed and chemically weathered rock.

The method requires construction of a geologic section in which rock is classified according to the expected physical condition. Costs for excavating each of the physical classes appearing on the geologic section are then obtained from the appropriate cost curve.

Application of this method to several recent tunneling projects has in each instance yielded an estimate falling within the spread of contractors' bidding and in many instances lying near the center of the bid spread.

SIGNIFICANCE OF S^{32}/S^{34} RATIOS ON THE ORIGIN OF SULFIDES IN URANIUM DEPOSITS OF THE COLORADO PLATEAU

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The S^{32}/S^{34} ratios have been determined for a suite of more than 50 sulfide samples, collected predominately by R. Coleman, U.S. Geological Survey, from the Colorado Plateau and Wyoming. All ratios are compared to the standard of 22.21 for troilite from the Cañon Diablo meteorite. Information on the geologic and mineralogic occurrence of each sample is available on punched cards.

A summary of some of the results is as follows:

Happy Jack mine	7 samples	S^{32}/S^{34} = 22.73 to 23.32
Hidden Splendor mine	5 samples	S^{32}/S^{34} = 23.10 to 23.18
Mi Vida mine	6 samples	S^{32}/S^{34} = 23.14 to 23.27
A.E.C. #8 mine (Temple Mtn.)	4 samples	S^{32}/S^{34} = 22.63 to 23.04
Lucky Mac mine	4 samples	S^{32}/S^{34} = 22.85 to 23.28

The samples are predominately pyrite and marcasite, but chalcopyrite, covellite, and bornite are included even though the sulfide mineral species appears to have no relationship to the specific ratio

obtained. There is, furthermore, no indication of a difference between ratios obtained from sulfides collected within uranium ore zones in comparison to ratios of sulfides occurring in either adjacent or distant barren uranium ground. The formations (Triassic to Eocene) from which the samples were collected have no obvious correlation with the ratios.

The significance of these ratios upon the genesis of the sulfides is not conclusive but highly suggestive that the source of the sulfur is from H_2S, derived from anerobic bacteria. Presumably the H_2S was being formed as early as during diagenesis of the sediments during which time anerobic bacteria fed upon sulfate waters (possibly connate in nature) and liberated H_2S which is highly but variably enriched in S^{32} as is indicated by the high and relatively broad range of ratios measured. At a later stage, as the ore solutions moved through the more permeable channelways, sulfides were formed by reactions between iron (and in some cases copper) ions transported in the solutions and the highly effective reducing agent of H_2S.

HYDROTHERMAL ZONING OF LEAD IN THE MANGANESE ORES OF THE LUIS LOPEZ DISTRICT, SOCORRO COUNTY, NEW MEXICO*

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The late Tertiary or Quaternary manganese deposits of the Luis Lopez district, located about 8 miles southwest of Socorro, in central New Mexico, are an example of the occurrence of manganese oxide minerals as vein fillings or as stockworks of veinlets cementing breccia associated with fault zones in rhyolite.

The host rock for more than 95 per cent of the manganese occurrences is a massive rhyolite. The ores consist mainly of the banded botryoidal complex manganese oxide minerals hollandite and cryptomelane, some coronadite, the lead manganous manganic oxide, and associated minor calcite, quartz, anhydrite, and barite. The ores are considered to be of hydrothermal (epithermal) origin.

The lead content of the ores in the Luis Lopez district ranges from 0.09 to 7.82 per cent. The ores are high in lead in the northern and northwestern parts of the district and contain very little lead in the southern and eastern parts of the district. Gradation of lead content between the two areas is shown by assays of samples from 15 localities.

Sixteen samples from one large mine in the northwestern part of the district show no systematic lateral zoning of lead content, but there is an indication that the lead content increases with depth beneath the surface.

It is probable that other late Cenozoic epigenetic manganese deposits of the so-called "black calcite" type may be zoned with respect to lead or other metals, such as tungsten or cobalt, which commonly occur in association with complex manganese oxides.

STRATIGRAPHY AND STRUCTURE OF THE NEW JERSEY COASTAL PLAIN

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Before 1951 it was believed that the Cretaceous and Tertiary strata of the New Jersey Coastal Plain dipped gently to the southeast in a simple monoclinal structure, although the possible existence of closed structures of either anticlinal or stratigraphic type was well recognized. In 1951 the Transcontinental Gas Pipeline Corporation decided to test this possibility because of the value any closed structure would have for gas storage. Twenty test wells were drilled in an area bounded roughly by Browns Mills, Toms River, Cedar Bridge and Tabernacle. Although none of these wells

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penetrated the full thickness of the sedimentary column, they were adequate to show that within 2000 feet of the surface there is no closed structure within the area mentioned. The drilling also provided valuable information on the stratigraphy, the most significant being the discovery at a depth of about 1650 feet near Harrisville, New Jersey, of a marine phase of the Raritan Formation consisting of silt and some limestone carrying a fauna of mollusks and other invertebrates similar to those occurring in the Woodbine Formation of Texas.

PETROGRAPHIC EXAMINATION OF COAL PELLETS PREPARED BY COMPRESSING PLASTICIZED PARTICLES OF CRUSHED COAL*

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Samples of crushed coal for microscopic examination are agglomerated into cylindrical pellets or briquets by the application of heat and pressure in the presence of a plasticizing agent. Under given briquetting conditions the quality of the pellets appears to depend mostly on particle size and rank. For the majority of coals studied the pellets are strong and compact so that both polished and thin sections can be readily prepared from them.

Under reflected light the contrast between macerals in the briquets is considerably better than in the standard crushed coal pellets which have a plastic bond. The particles of coal in the briquets are in direct contact, and the relative reflectance of the coal components can be more easily compared. The point-count method of analysis is particularly adaptable to these specimens; hence, rapid quantitative maceral determinations are possible.

A comparative study of the reflected- and transmitted-light techniques, carried out on polished and thin sections prepared from the same specimens, shows that the results of the two methods do not differ greatly for bright coals, but for duller coals the differences progressively increase with the durain content.

RARE-EARTH DEPOSIT AT THE SCRUB OAKS MINE, MORRIS COUNTY, NEW JERSEY

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A rare-earth deposit in the Scrub Oaks iron mine, Morris County, New Jersey, was mapped and sampled in 1955. The rare-earth minerals are mainly in coarse-grained magnetite ore and in pegmatite adjacent to the ore, and they form discrete irregular-shaped bodies that apparently follow the plunge of the main tabular magnetite ore body at the north end of the mine.

The principal minerals of the deposit are quartz, magnetite, hematite, albite-oligoclase, perthite and antiperthite, and the rare-earth minerals doverite, xenotime, and bastnaesite with intermixed leucoxene. Zircon, sphene, chevkinite, apatite, and monazite are rare-earth minerals of lesser abundance in the ore.

The rare-earth elements are partly differentiated into cerium-rich bastnaesite, chevkinite, and monazite, and yttrium-rich xenotime and doverite. Apatite, zircon, and sphene contain both cerium and yttrium group earths.

Eleven radioactive samples of magnetite ore and rock average 0.009 per cent uranium, 0.062 per cent thorium, 1.51 per cent combined rare-earth oxides including Y_2O_3, and 24.8 per cent iron.

The rare-earth-bearing radioactive magnetite ore is believed to be a variant of the main magnetite ore body. The rare-earth minerals were deposited contemporaneously with the iron ore minerals.

The age of the deposit is believed to be late Precambrian.

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SYSTEM Mn-O-OH

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The synthesis, stability, and interconvertibility of the oxides and hydroxides in the Mn-O-OH system have been studied in about 500 runs under varying conditions of water pressure, oxygen pressure and temperature. *P-T* curves have been determined for the pyrolusite = bixbyite + O_2 (equil. at 540°C at 100 atm. O_2), manganosite = pyrochroite + H_2O (equil. at 390°C. and 1000 atm of H_2O), manganite=bixbyite + H_2O (equil. at 270°C. and 1000 atm H_2O) reactions. The reversibility of the groutite-ramsdellite reaction has been effected, and the existence of an intermediate compound between groutite and ramsdellite demonstrated. Thermodynamic data for some of the reactions in this system have been checked against the experimental work.

A hitherto unreported compound in this system appears under a wide variety of conditions, and its chemical and X-ray properties have been studied. This phase, ramsdellite, δ, ρ, γ-MnO_2, and probably hydrohausmannite are metastable phases under all conditions.

HYDROTHERMAL STUDY OF DEHYDRATED NATROLITE

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Dehydrated natrolite powder (amorphous) formed by heat treatment of the natural mineral was treated in a pressure vessel with water in the temperature region between 150°C. and 300°C. for various lengths of time ranging from 6 to 144 hours at various pressures. The reaction products were examined by X-ray and dehydration methods.

At 150°C. and 200°C. in the shorter runs some natrolite is formed; in the longer runs the amount decreases, and analcite predominates (neither phase is well crystallized). At temperatures of 250°C or higher very little natrolite can be detected, and analcite is formed in all the runs.

The effects of the hydrogen-ion concentration on the reaction products were also examined. In alkaline media, at 200°C. analcite and natrolite were formed; in acidic media, only natrolite appeared as the reaction product.

Ultramarine and sodalite were also treated hydrothermally with water. At 200°–250°C., partial decomposition to analcite took place.

These data suggest that if natrolite has any field of stability it is probably below 200°C.; its formation appears to be favored by the presence of seeds or by a low pH (equivalent to the presence of some other ions).

DIFFERENTIAL THERMAL ANALYSIS OF SPHALERITE

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The effect of iron content on the differential thermal peak temperature of sphalerite has been investigated. Samples were heated in air using a slightly modified technique described by Kopp and Kerr (1957). Several sphalerite samples ranging in iron content from less than 0.1 per cent Fe to 13.2 per cent Fe were subjected to differential thermal analysis. Quartz was used as an internal standard. Peak temperatures were observed to decrease from 821° ± 3°C. for sphalerite containing less than 0.1 per cent Fe to 767° ± 3°C. for sphalerite containing 13 per cent Fe. A curve has been developed showing the relationship between peak temperature and iron content.

In determining peak temperature close control of grain size, heating rate, and sample weight is essential. Peak temperatures are subject to a decrease with grain size especially below 44 microns diameter (No. 325 sieve). A suitable grain size selected for analysis lies between No. 100 and No. 120 sieves (125–149 microns). Peak temperatures decrease with decreasing heating rate at about 3°C. per °C. per minute. It is possible to apply this correction factor between 7°C. per minute and 12°C. per minute. Samples weighing between 40 and 60 milligrams vary less than 3°C. in peak temperature. However, below 40 milligrams, the peak temperature decreases.

GRAVITY TECTONICS IN THE NAUKLUFT MOUNTAINS, SOUTH WEST AFRICA

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The early Paleozoic? Nama beds of the Naukluft Mountains in South West Africa show intense deformation of Alpine type.

The crystalline basement underlying these rocks seems little disturbed. Its upper surface forms a basin-shaped depression. The intensity of folding in the overlying Nama increases from the basement up, then decreases again in the neighborhood of a practically undeformed unconformity which separates the Nama here into two folded units. Above the unconformity is a strikingly uniform and little-disturbed dolomite zone. Above the dolomite the intensity of deformation once more increases until it reaches its greatest intensity in this upper deformed unit. The folds delineate a cascading movement from the topographically higher northern hinterland and form a great arc in front of the steepest slope of the basin, overriding the undeformed Nama of the southern foreland in a number of thrust sheets and overfolds.

These observations, based on detailed mapping under exceptionally favorable exposure conditions, bring out a movement pattern which is quite plainly controlled by the shape of the basin. Such a pattern is best interpreted as due to plastic flow under the influence of gravity.

ECOLOGY OF RECENT MARINE OSTRACODES IN THE BIMINI AREA, GREAT BAHAMA BANK

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Areal distribution of kinds and abundances of both living and dead ostracodes in the Bimini area have been mapped on a photogrammetric base. The associated organisms, sediments, and ecological factors have been studied, and their effect on ostracode distribution interpreted. Knowledge thus acquired should be directly applicable to the interpretation of depositional environments of fossil ostracodes as the warm shelf sea present in this area is probably typical of that in existence during the formation of many limestone strata.

Nineteen species of the suborder Myodocopa, 15 new, are a major part of the living fauna, but their shells are not preserved. The areas containing the largest numbers of dead ostracodes do not coincide with the areas of maximum abundances of living ostracodes. This is due primarily to varying rates of skeletal accumulation from organisms other than ostracodes. The number of dead ostracodes in the sediment is unusually large, and the composition of the community is different where metahaline or brackish-water conditions exist or have existed. Salinities which affect the composition of the ostracode population aslo affect the distribution of many other organisms.

Normal temperatures of the Bimini area probably do not influence the ostracode distribution, but unusually low winter temperatures may have a catastrophic effect on sensitive species. Ostracodes are extremely rare in areas covered by oölite sand and in shifting bioclastic sand. Small variations in pH and water depth have little effect on ostracode distribution.

COMPOSITION OF MAGMATIC GASES AT 600°C

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By assuming that magmatic gases are in approximate equilibrium with the common minerals of contact-metamorphic and hypothermal deposits it is possible to place limits on their composition. The partial pressure of oxygen, limited chiefly by assumed equilibria among iron minerals, ranges from about 10^{-16} to 10^{-21} atmospheres. Total amounts of sulfur, chlorine, fluorine, and carbon may be guessed from the composition of volcanic gases; then free chlorine has a range of pressures from 10^{-9} to 10^{-12}, free sulfur from 10^{-1} to 10^{-6}, and methane from 10^{-6} to 10 atmospheres. In the more oxidizing part of these ranges such minerals as magnetite, hematite, and anhydrite are stable; in the reducing part, minerals like pyrrhotite and pyroxenes. The occurrences of tungsten as tungstates rather than sulfides, of molybdenum as a sulfide rather than molybdates, of tin as the dioxide rather than sulfides, and of barium as sulfate rather than silicates are all consistent with these figures.

Maximum concentrations of heavy metals in such a magmatic vapor may likewise be calculated, again by assuming equilibrium with solid phases and by further assuming that liquid phases play only a minor role. Most of the metals would be present as chlorides, the amount of each being determined not only by the simple vapor pressure of the chloride but also by equilibrium with sulfides, oxides, and silicates. The permitted amounts of chlorides in the vapor are sufficient to account for large-scale vapor transport of many but not all the common ore metals.

DOLOMITES

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Two principal modes of occurrence account by volume for more than 90 per cent of sedimentary dolomites.

(1) Primary dolomites pene-directly deposited from sea water build initially unconsolidated but structurally organized sediments pale gray or creamy, very fine (5 microns), thinly bedded (under 0.5 cm) with no fossil relicts but frequent evidence of subaerial truncation or eolian action.

(2) Secondary dolomites coarser dark gray to black, containing fossil "ghosts", always interbedded with primary dolomites are produced by early syngenetic dolomitization of unconsolidated limestones.

Both types interlayered in subequal proportions average 3000 feet within the Cambro-Ordovician of the peripheries of the Canadian-American and Siberian shields. They inhabit thickly Mississippian-Permian on Russian Platform, Ural geosyncline, and Ancestral Rockies. They cover more than 5 million square miles.

In Central Pennsylvania Upper Cambrian "Gatesburg" shows 55 cycles of alternating primary and secondary dolomites within 700 feet, and Lower Ordovician "Nittany" shows 70 cycles within 450 feet.

Satellitic rock types such as eolian quartzitic layers, small algal reefs, and thixotropic intraformational conglomerates may occur at *definite* horizons within one basic cycle.

Super cyclicity sways entire formations from almost pure limestone into almost pure primary dolomite.

Genetically a classical cycle begins in a dry climate in relatively "deep", normal sea water forming limestones, followed by shallowing and supersalinity precipitating primary dolomite above while concurrently underlying unconsolidated limestones are dolomitized from the top down, producing secondary dolomites.

The ultimate genetic cause is tectonic positive subregional cyclic downdropping alternating with warped fill-in.

COMPOSITIONS OF ALKALI FELDSPARS IN SOME IGNEOUS ROCKS

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Alkali feldspars have been carefully separated by hand picking from specimens of the Mount Pennell area of the Henry Mountains, Utah; the La Sal Mountains, Utah; the Huntington Lake area, California; Tertiary and Nevadan intrusives from the southern part of the Idaho batholith; soda granite near Questa, New Mexico; sanidine pegmatite in Grant County, New Mexico; monzonite porphyry near Hillsboro, New Mexico; and Schultze granite near Miami, Arizona. Bulk compositions of these feldspars, based on partial analyses, show a close correlation with the $(\bar{2}01)$ X-ray intensity ratios of the potassic and albitic phases where both phases occur in a morphological crystal and can be detected by X ray diffractometry. The compositional ranges of these alkali feldspars (minimum 20 per cent Or), even within a small homogeneous intrusive, suggest differentiation and emphasize the difficulties of petrographic sampling. Although the coarseness of the perthitic intergrowths is roughly correlative with the relative age and inferred cooling conditions, the unmixing of the alkali feldspars into sodic and potassic end members has produced no comparable variation in bulk feldspar composition. Compositions of the Mount Pennell feldspars suggest primary crystallization of two alkali feldspars. For the Questa soda granite the feldspar compositional range appears to result from primary differentiation, followed by a potassium-rich pegmatitic stage, and in turn by later albitization.

UPPER STABILITY CURVE OF COVELLITE

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The upper stability curve of synthetic covellite has been found to pass through the following points: 507°C.—925 mm Hg (invariant point where the four phases $Cu_9S_5 + CuS + L + V$ are stable), 510°C.—500 bars, 515°C.—1000 bars, and 525°C.—2000 bars. The reaction taking place at this univariant equilibrium curve may be formulated:

$$\text{Covellite} \rightleftarrows \text{digenite} + \text{liquid}$$

Covellite grown in closed, evacuated, silica tubes is commonly massive and rarely shows crystal faces. Single crystals were grown at high pressure in collapsible gold tubes. These crystals are less than 0.1 mm long and appear to be hexagonal plates. The powder X-ray diffraction pattern is identical with that of natural covellite. Digenite grows as blue to black well-developed crystals which always occur as octahedra modified by cube faces. The composition of digenite determined by an X-ray method is, within experimental error, Cu_9S_5. The liquid formed by decomposition of covellite in collapsible gold tubes appears, when quenched, white to yellow and consists of almost pure sulfur. X-ray powder diffraction patterns made at room temperature of this material are always that of orthorhombic sulfur. The occurrence of covellite in sericitized host rocks is accounted for by comparing the upper stability curve of covellite with that of 2M muscovite (sericite).

AGE OF THE PIEDMONT AND SOUTHERN APPALACHIANS

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The rocks in southeastern United States are being studied as part of an extensive radioactive age-determination program. Potassium-argon determinations have been made on mica from igneous

and metamorphic rocks ranging from Virginia to Georgia. Results show that granite was intruded into the Piedmont terrain in eastern Georgia about 250 m.y. ago. Apparent ages of 320 m.y. to 370 m.y. are indicated for the metamorphic series in western Virginia and North Carolina, as well as for the pegmatite swarms in the Spruce Pine and Bryson City districts, North Carolina. Some of the crystalline rocks of the basement complex in extreme western North Carolina and eastern Tennessee are considerably older than this. It is concluded that, since many ages found in New York, New England, and the Maritime Provinces are similar to those found in the South, the Paleozoic regional metamorphisms have affected very large portions of the eastern seaboard.

CHEMICAL UNCONFORMITIES

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Through the co-operation of commercial producers of carbonate rocks reliable analyses of outcrop and core samples numbered in the thousands and keyed to the stratigraphy have become available for scientific study. These analyses include Devonian limestones in Michigan and Ohio; Ordovician limestones and dolomites in Pennsylvania, Maryland, West Virginia, and Virginia; and Tertiary limestones in Cuba and Jamaica. As a general rule the basal few feet of these limestones is higher in silica and magnesia than are the overlying strata. The sulfur content is also higher in most instances. The lithologic differences may be so slight that they are not visible by megascopic examination. It has been possible therefore to map formation contacts by chemical analyses where they are not otherwise determinable.

It is suggested that the higher percentage of impurities toward the bottom of the carbonate rock formations is due to the presence of inwashed fine clastic and organic material. The chemical unconformity is to the carbonate rock section as the basal conglomerate is to the coarse clastic rock section.

CRETACEOUS AMBER FROM THE ARCTIC COASTAL PLAIN OF ALASKA*

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Amber is widespread in latest Early Cretaceous and earliest Late Cretaceous rocks, probably Chandler Formation, between Lat. 69° 40′ N. and 70° 5′ N. along the Kaolak River and on the lower Ketik River above Wainwright, Alaska. Cretaceous rocks in this area are primarily gray mudstone and shale with abundant coal and carbonaceous shale. Sandstone, siltstone, metabentonite, and calcareous concretions are less prominent. All rocks except mudstone and shale form nonpersistent lenses. Plant fossils belong to three well-defined florules. Cycadeoids, largely confined to the northern and southern extremities of the area, suggest an Early Cretaceous age. Angiosperm and taxodiaceous florules, largely confined to localities between 70° 10′ N. and 69° 47′ N., suggest a Late Cretaceous age. Preliminary analyses of scattered samples show ubiquitous coniferous pollen and spores in fine-grained and coaly rocks. Vertebrate fossils are absent, and only one *Ostrea* was obtained from residual materials. Amber occurs in clay rocks, carbonaceous sediments, and coal in marked association with taxodiaceous fossils from 69° 40′ N. to 70° 10′ N. It is considered derived from both Early and Late Cretaceous conifers. Insects occur sparsely in the amber. Amber also occurs with water-logged plant material on gravel bars and is redeposited in Pleistocene sediments.

* These studies were aided by a contract between the Office of Naval Research, Department of the Navy, and the Arctic Institute of North America. Reproduction in whole or in part is permitted for any purpose of the United States Government.

EFFECTS OF CHROMIUM SUBSTITUTION IN CHLORITE

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Chromium substitution in natural chlorites has a minimal range between 0 per cent and 8 per cent Cr_2O_3. The extent of this substitution may be determined from the relative intensities and the interatomic spacings of basal reflections, utilizing standard X-ray powder techniques.

The majority of chromium chlorites contain octahedrally substituted chromium, although lower water pressures and higher temperatures may result in tetrahedral chromium. X-ray-powder and differential-thermal data are especially useful in differentiating between the two types of substitution and in determining the extent of this substitution in either position to within ± 0.5 per cent Cr_2O_3.

Chromium substitution causes (1) significant intensity variations which permit a distinction between octahedral and tetrahedral chromium, (2) a general lattice expansion which is greater for octahedral than for tetrahedral chromium, (3) an increase in the alpha and gamma indices of refraction of approximately .010 from 1 per cent to 8 per cent Cr_2O_3, (4) a general thermal stability decrease of the chlorite lattice with increasing chromium content, the brucite layer breaking down at higher temperatures for tetrahedral chromium, and (5) a change in the optic sign from positive to negative at approximately 5.9 per cent Cr_2O_3.

A classification is proposed based both on the position of chromium substitution and on total chromium content.

DETAILED GRAVITY MEASUREMENTS IN THE TETON RANGE AND JACKSON HOLE, WYOMING

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Terrain-corrected Bouguer anomalies, based on 280 observations, show a gravity maximum (least negative value -185 mgals.) associated with the Precambrian complex of the Teton Range and a minimum (most negative value -240 mgals.) over Jackson Hole from the northern end of Jackson Lake to Jackson, Wyo. This indicates that this basin and range feature is not in local isostatic adjustment. The interpretation of the residual anomalies of the basin places an upper limit on the thickness of sediments in Jackson Hole at about 11,000 feet of Tertiary and Quaternary material. A gradient of 10 mgals./mile on the western margin of the basin verifies the existence of the Teton fault as a high angle normal fault. In the vicinity of Jenny Lake the position of the gradient shows that the major displacement of the fault is 1 to 2 miles east of the location indicated by the present topography. It is suggested that in this area the fault is a step fault. A northwestward-trending gravity maximum transects the Jackson Hole minimum in the vicinity of Blacktail Butte, showing that the Laramide fold structures of the Gros Ventre Range continue across Jackson Hole.

KEEWATIN ICE DIVIDE

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West of Hudson Bay in the region surrounding the "Keewatin glacial centers", eskers and glacial-flow features are arranged in a roughly radial pattern that heads in a linear zone or ice divide; minor moraines form a semi-elliptical pattern around this ice divide. The ice divide is 400 miles long and extends southeast from Hudson Bay at Lat. 66° to a point 150 miles inland at Lat. 61°. The principal directions of glacial flow (recorded by drumlinoids, striae, stoss and lee, etc.) were southeastward

between the ice divide and Hudson Bay, northwestward to northward between the divide and the arctic coast, and southward to westward around the southern end of the divide. No evidence has been found of the northwestward glacial movement out of Hudson Bay suggested by Bird (1953), Downie *et al.* (1953), and Taylor (1956).

The minor moraines, eskers, and most glacial-flow features record the trends of successive positions of the margin of the ice sheet and of successive ice movements near the margin during deglaciation. On this basis, the ice divide is the zone occupied by the last glacial remnants rather than a center of ice dispersal.

As the ice sheet waned, the glacial margin first retreated northward and eastward across the southern part of the region and then southeastward and northwestward toward the ice divide farther north. The north-westward marginal retreat near Hudson Bay probably resulted from the entry of the sea into the Bay.

GEOLOGIC AND HYDROLOGIC HISTORY OF THE TERTIARY LIMESTONE OF NORTH CAROLINA*

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The Castle Hayne limestone of middle and late Eocene age and limestone of the Yorktown Formation of late Miocene age together constitute a homoclinal artesian system in the North Carolina Coastal Plain. Reconstruction of the gross geologic and hydrologic history since Eocene time shows widespread karst development on the Castle Hayne during Oligocene and early Miocene time when a water-table circulatory system prevailed. Since late Miocene, when impermeable clays of the Yorktown Formation mantled the limestone, artesian conditions have controlled circulation of water moving from the westward recharge area down dip, but the water moves at an extremely slow rate because of poor artesian-discharge facilities. During Recent time a few streams, including Trent River in Jones County and Neuse River in Craven County, have incised their channels in the limestone to produce locally a new water-table circulatory system.

To be vulnerable to solution, limestone may be under either water-table or artesian conditions, but in either case (1) it must have a source of recharge, (2) it must transmit water, and (3) it must discharge water. Of these requirements the facilities for discharge are especially critical because means of escape are necessary before water can circulate and remove mineral matter in solution. Structural conditions both favorable and unfavorable for discharge occur in some limestone formations contemporaneously. Careful study of the geologic history of a limestone terrane, with special attention to discharge facilities that have existed at different times and places, should simplify many economic problems concerning the limestone.

DISSIMILARITY OF CONTINENTAL AND OCEANIC ROCK SUITES

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Recent papers cite the similarity of rocks, particularly andesites, in continental and oceanic regions. Some rocks of oceanic islands are indeed andesites according to the Rosenbusch classification, but they differ markedly from typical continental andesites.

The oceanic "andesites" consist essentially of sodic plagioclase, monoclinic pyroxene, magnetite, ilmenite, and a little olivine. Color index is between 35 and 60, generally greater than 45. Most contain normative olivine, and none contain more than 2 per cent normative quartz. Niggli *qz* values range from −13 to −58. Independent grains of alkalic feldspar are absent, although the late-crys-

* Publication authorized by the Director. U. S. Geological Survey.

tallized plagioclase probably contains potassium. Late magmatic or deuteric phlogopitic biotite is widespread, but not abundant. Tiny grains of pale hornblende and a riebeckitelike amphibole are rare. Hypersthene has not been found. The writer previously called these rocks "andesine andesite" and "oligoclase andesite" according to the average composition of the feldspar. Because the use of the name "andesite" for them seems to cause confusion, a different name is desirable. Those containing oligoclase may be termed mugearite. The most appropriate name for those containing andesine seems to be andesine basalt.

All members of the oceanic suite are present also in continental regions. However, the calc-alkaline suite typical of orogenic regions of the continents—hypersthene andesite, hornblende andesite, dacite, rhyodacite, and rhyolite—appears to be nearly absent or absent within the true ocean basins. Soda "rhyolites" of Easter Island and Samoa intergrade with soda trachytes; thus although quartzose differentiates do occur, they are alkalic, not calc-alkaline.

ORIENTATION OF ANISOTROPIC MINERALS IN A STRESS FIELD

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The equilibrium orientation of an anisotropic mineral in a stress field is one in which the potential energy of the external forces, plus the potential energy of deformation, is minimized. For materials obeying a linear elastic stress-strain law, the minimum total potential energy is equivalent to a maximum Helmholtz free energy in an isothermal system or a maximum internal energy in an adiabatic system. The minimum potential energy theorem is applicable to the orientation of minerals in rocks undergoing plastic deformation provided temperature and elastic strain are sufficient parameters to describe the thermodynamic state of the mineral undergoing isothermal plastic flow. Using measured elastic constants of calcite the thermodynamic theory of mineral orientation predicts that the *c* axes of calcite should show a maximum parallel to the axis of compression in a uniaxial compression and should form a girdle in the plane of compression in the case of radial compression. Both predictions are in agreement with experimental results. The theory also predicts that quartz in uniaxial compression should orient in a girdle perpendicular to the axis of compression and that the *c* axes of quartz in radial compression should be perpendicular to the plane of compression.

EXPERIMENTAL PHASE-RULE STUDIES INVOLVING TRANSITIONS OF VARIOUS KINDS

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In an attempt to check the applicability of the Clapeyron relationship to transitions of various types the following experiments have been carried out: (1) measurement of the *p-t* dependence for the transition by static or dynamic phase equilibrium methods; (2) measurement of the volume change by high temperature X-ray methods; (3) measurement (in a few cases) of the heat of transition by a calibrated DTA method using dilution techniques. The following phases have been studied: CsCl, AgI, K_2SO_4, Na_3AlF_6, SiO_2-cristobalite$_{3c}$, GeO_2, ZnS.

Agreement between thermochemical values of the enthalpy of transition and those obtained by using the Clapeyron relationship is poor in most of these cases; it cannot be decided whether this is due to poor ΔH values or to the deviation of these transitions from ideal first-order behavior.

The validity of Raoult's law and the detectability of the two-phase regions below the solidus in the case of rapid transitions have been studied by determining the equilibrium diagrams for the

systems RbCl-CsCl, and Na_2WO_4-Na_2MoO_4 (with three transitions). The two-phase region can be studied directly in the former, while in the latter it must be vanishingly narrow if present.

RADIOACTIVE MINERALS OF NEW JERSEY

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Radioactive minerals are widespread in the Precambrian metamorphic rocks of New Jersey near West Milford, Passaic County; near Chester and Tanners Brook in Morris County; Pattenburg in Hunterdon County; and Marble Mountain near Phillipsburg in Warren County.

Uraninite, kasolite, uranophane, metatorbernite, and fluorescent opaline silica occur at West Milford in discontinuous bands or stringers, as much as 4 inches wide, in the magnetite and allanite-rich bands of the Byram granite gneiss. Uraninite and kasolite are present as round pellets; uranophane and opaline silica coat fracture surfaces. Locally the biotite-rich granite gneiss of the Byram contains notable amounts of monazite.

Monazite and zircon form the bulk of a rust-brown rock near Chester and Tanners Brook in Morris County.

Metamict uranian fergusonite and metamict zircon occur as scattered grains in Precambrian granite gneiss at the Pattenburg quarry.

On Marble Mountain, near Phillipsburg, a radioactive thorium silicate is microscopically intergrown with hematite in serpentine schist containing coarse black or dark-brown tourmaline. It occurs as abundant red grains from a few millimeters to about a centimeter across, scattered in bands several inches thick. The mineral is metamict and after ignition gives a distinct huttonite X-ray powder-diffraction pattern.

The radioactive minerals in the Precambrian rocks are associated with magnetite and hematite, except those at Pattenburg and the monazite-zircon occurrences. The West Milford occurrence is one of the more promising concentrations of uranium in the Precambrian rocks of New Jersey.

PRELIMINARY REPORT ON ILMENITE-BEARING SANDS FROM THE COASTAL PLAIN OF NEW JERSEY

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Investigation of the Cohansey (Pliocene?) and Kirkwood (Miocene) sands in Ocean and Burlington counties has revealed substantial percentages of heavy minerals. Exploration by the New Jersey Geological Survey has been carried out over an area of approximately 10 by 30 miles. To date 200 holes have been hand-augered with an overall average content of 3.0 per cent heavy minerals which contain an average of 45–56 per cent TiO_2. Ilmenite, which has an average TiO_2 content of 52–58 per cent, ranges from 65–85 per cent of the heavy-mineral constituents. Associated minerals include leucoxene, zircon, sillimanite, kyanite, rutile, staurolite, and tourmaline. Material size ranges from fine gravel to very fine micaceous sand, with the best values occurring in yellowish-gray to grayish-brown fine to medium sand.

Preliminary work suggests that high-grade concentrations in the Cohansey Formation occur in stream channels of varying widths, with moderate to low values in the adjacent material. Concentrations in the Kirkwood Formation appear to be of marine origin.

Probable source areas include portions of the Precambrian, Paleozoic, Triassic and possibly the outcrop limits of the underlying coastal plain formations.

At least four potential ore bodies of 1000 acres or more, with more than 1 per cent TiO_2 content to a depth of 20 feet, are indicated thus far.

LOWER AND MIDDLE CAMBRIAN STRATIGRAPHY IN NORTHERN UTAH AND SOUTHEASTERN IDAHO

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The stratigraphic succession of Lower and Middle Cambrian sediments in northern Utah and southeastern Idaho as determined from 13 measured sections includes the basal medium- to coarse-grained Prospect Mountain quartzite overlain by interbedded fine- and coarse-grained clastics (Pioche Formation) that in turn are overlain by several hundred to a few thousand feet of carbonate rocks with a few thinly interbedded layers of fine clastics. The carbonate sequence includes the Langston Formation, Ute Limestone, Blacksmith Dolomite, and Bloomington Formation.

Known occurrences of fossils are listed for the formations. Seventeen faunal groups are identified, and a sequence of faunizones, including four new or revised units, is proposed.

Cambrian deposits may be separated into (1) orthoquartzite; (2) greenish-brown, micaceous and arenaceous shale; (3) brown-weathering, calcareous sandstone; (4) rusty-brown-weathering dolomite; (5) green and buff fissile shale; (6) calcareous black shale; (7) mottled, silty, aphanitic, thinly bedded limestone; (8) *Girvanella* limestone; (9) intraformational conglomerate; (10) oölitic limestone; (11) "undifferentiated limestone"; and (12) "undifferentiated dolomite" facies.

All these sediments probably were deposited in a shallow, chiefly transgressive, though oscillating, sea. This sea transgressed a low-lying but mature topography eastward to western Utah by earliest Cambrian (pre-"*Olenellus*"?) time and to eastern Utah by the end of Early Cambrian time. The area remained submerged during Medial Cambrian and much of Late Cambrian time.

SEDIMENTARY PETROLOGY OF THE MISSISSAGI QUARTZITE IN THE BLIND RIVER AREA, ONTARIO*

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The attitudes of more than 1500 cross-beds were measured in the Huronian Mississagi quartzite at more than 150 localities on the North Shore of Lake Huron. The mean current direction ranged from 110° in the Upper Mississagi to 160° in the Lower Mississagi. Cross-bedding and pebble orientation measured underground in the uranium ore horizon of the Lower Mississagi and the diminution in maximum pebble size and percentage of black chert measured in Upper Mississagi conglomerate outcrops support the sedimentary trend established through cross-bedding. Assuming that the pebble size increases exponentially toward the source, the data show that the source area was on the order of 200 miles west-northwest of Blind River.

The type of cross-bedding, megaripple marks, regional uniformity of current directions, and variation in size and composition of conglomerate pebbles favor a fluvial origin for the Mississagi sands. The fine laminations and graded bedding suggest a marine submergence or a large lake for the deposition of the Middle Mississagi silts and argillites. The ore-bearing conglomerates are believed to represent gravels deposited in ancient stream beds. Semicontinuous gravel beds were formed by migration of stream channels by lateral corrasion.

The similarity in trend of current directions in the Mississagi as measured in cross-bedding, ripple marking, pebble size and composition, and pebble orientation, and the trends of ore horizons as outlined by drilling and mine development suggest that the two are related; this is strong evidence of a syngenetic origin of the ore.

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* With permission of the Provincial Geologist, Ontario Dept. Mines.

SIZE DISTRIBUTIONS OF SOME MINERAL GRAINS FROM A BEACH, LORRAINE, ONTARIO

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The long axes of approximately 4500 grains of quartz, garnet, clino-pyroxene, hornblende, and hypersthene were measured; these grains represent 150 samples disposed on a 4- by 9-foot grid from three layers in the upper foreshore of the beach at Lorraine, Ontario. Nine of the 15 layer grain-size distributions were essentially normal.

Analyses of variance of these size distributions using a two-crossed classification together with size correlations and sorting indicated that two of the layers had probably been reworked after deposition.

Theoretical and empirical hydraulic equivalent sizes were computed and compared using both quartz and garnet as bases. The theoretical differences between means of the grain-size distributions were found using a hydraulic equivalence formula developed from Rubey's fall-velocity equation. This formula is:

$$\phi_1 - \phi_2 = 1/X\ (\log_2 D_1 - \log_2 D_2);$$

where ϕ = mean grain size in phi units; D = density of mineral minus density of water; X = a function of grain-size range.

The observed hydraulic equivalent sizes based on quartz for the two reworked layers were too low, perhaps because of selective removal of the coarser quartz grains. For the third layer the observed values were too high, apparently caused by the low relative availability of coarser heavy minerals. In contrast, the values based on garnet agree fairly well indicating that deposition from suspension controlled the heavy-mineral size relationships.

TRIASSIC ALLUVIAL FANS IN PENNSYLVANIA*

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The Brunswick Formation (upper Newark) near the Delaware River and the equivalent Gettysburg Formation from the Susquehanna into Maryland are chiefly red shale and siltstone. Between these areas, in Lancaster, Lebanon, and southern Berks counties, shale is scarce, and thick conglomerates are interbedded with sandstones.

In the lower Gettysburg the thickest conglomerates occur about two centers 25 miles apart. (1) Southeast of Reading is more than 5000 feet of lenticular conglomerates with sandstones. Each member extends about 12 miles, fingering out east and west. (2) West of there, Furnace Ridge south of Lebanon comprises four conglomerate members with interbedded sandstone, 2300 feet thick. It extends 16 miles and grades into sandstone at both ends.

South of Reading the upper Gettysburg contains 6000 feet of cobble conglomerate deposited by a stream that entered the basin near the present Schuylkill. Laurel Ridge 10 miles west of Reading is a western extremity of this lens. Above Furnace Ridge are two centers of less extensive gravel deposition. One represents additional deposits by the stream that formed the Furnace Ridge members. The other indicates a new stream several miles farther west.

Pebbles are of Paleozoic quartzites and sandstones now exposed to the north. Attitudes of cross-bedding also indicate a northern source. Some facies have very limited distribution. "Shale conglomerate" only adjoins outcrops of Martinsburg Shale. Hardyston Quartzite cobbles are confined

* Published with the permission of the State Geologist, Pennsylvania Geological Survey

to areas near South Mountain west of Reading. Limestone conglomerate is extensive only near the Oley Valley limestone area.

SEDIMENTATION FEATURES IN PARADOX SHALES, SOUTHEASTERN UTAH

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Sedimentological studies were made of subsurface samples of the Pennsylvanian Paradox shales from seven wells in the southwest portion of the Paradox Basin in southeastern Utah. Sediment properties examined included grain size, carbonate content, clay minerals, and heavy-mineral content.

The section of the Paradox shales selected for study lies at or near the top of the evaporite section and consists of highly calcareous gray to black siltstones, shales and mudstones, and localized micaceous zones.

Size analyses show a decrease in median diameter northeasterly toward the center of the basin. The heavy-mineral and carbonate content of the shales also decreases in this direction.

There is an anomaly in the general sedimentary pattern in a small northwest-trending area characterized by an abnormally high concentration of heavy minerals, low-dolomite content, high-chlorite content, and markedly poor sorting compared to the near-shore and off-shore areas.

A progressive change in the clay minerals from near shore into the basin was noted as follows: montmorillonite with illite, chlorite and illite with montmorillonite, and chlorite and illite.

FOLIATION, BUBBLE TRENDS, AND DIRT ZONES AND THEIR RELATION TO GLACIER FLOW IN PART OF NORTH ICE CAP, NORTHWEST GREENLAND

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Planar and linear structures in glacier ice in a small area at the cliffed margin of North Ice Cap were studied during two field seasons. Data were obtained from the glacier surface, the face and toe of the cliff, and from tunnels near the base.

Foliation is expressed megascopically through differential distribution of bubbles, but planar and linear features of bubble orientation within a folia band do not necessarily parallel the boundaries of the band. Orientation and distribution of bubble features are variable in space and time: bubbly zones grade laterally into clear ice; clear ice changes to bubbly, and bubbly to clear with time.

Dirt is concentrated in the lower third of the cliff and within 20 m of the ice margin. It occurs in thin zones which offset folia; in others which the folia cross without offset; in some which parallel folia; and in thicker zones and in isoclinally folded thin zones which bear intersecting and parallel relationships to adjacent folia. Pods and lenses of cobbles and pebbles, unstratified sand and silt, and sand and silt in which original stratification is evident are also present. Some dirt is concentrated along shear zones in the ice, and its distribution is influenced by shear motion. Much has been concentrated by melting on earlier toe surfaces which were incorporated into the glacier as it advanced over them. Isoclinal folding of the dirt zones and of foliation, with axial planes dipping at moderate to low angles into the ice front, is interpreted to have resulted from nonlaminar flow.

GEOLOGIC OCCURRENCE OF MONAZITE AND XENOTIME IN THE SOUTHEASTERN STATES

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Monazite and smaller amounts of xenotime occur in the southeastern States in four general environments: in bedrock within the Piedmont and Blue Ridge provinces, in the stratigraphic units

of the Coastal Plain, in fluvial deposits within or adjacent to the Piedmont province, and in beach deposits of Pleistocene and Recent age.

The monazite-bearing bedrock includes pegmatites and massive and gneissic rocks of granitic composition; paragneiss and migmatite comprise a major part. The source rocks are localized principally in three belts. The most important, heretofore called the western monazite belt, was traced for 600 miles from Virginia into Alabama. An eastern belt was discovered and traced discontinuously for 300 miles in Virginia, North Carolina, and South Carolina. A third belt, in and adjacent to the Blue Ridge, has recently been recognized and traced with gaps through Virginia, North Carolina, and Georgia. These conclusions, constituting the principal part of this paper, are based mainly upon a study of granitic accessory minerals, panned from 55,000 pounds of saprolite and pulverized hard rock.

The fluvial deposits of the Piedmont province were mined in earlier years. Small amounts of heavy minerals that include monazite are present in all the units of the Coastal Plain. At one place near Aiken, South Carolina, these minerals have been reconcentrated by a local stream to produce a workable placer. Beach placers of ilmenite, rutile, and zircon are being worked at five sites in eastern Florida, and a small by-product of monazite is being recovered at two of these plants.

SOME ASPECTS OF THE OCCURRENCE AND GEOCHEMISTRY OF THE STERLING HILL ZINC DEPOSIT, SUSSEX COUNTY, NEW JERSEY

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The Sterling Hill ore body is mineralogically similar to its neighbor to the north in Franklin, New Jersey. It is an intricately folded, steeply plunging body in Precambrian graphitic, sparsely silicated, coarsely crystalline white marble. The marble is graphite free within 5 feet of ore. The ore is wrapped around a core of graphitic marble and an annular gneissic cylinder of varying mica, feldspar, hornblende, pyroxene, garnet composition.

Ore minerals are willemite, franklinite, and zincite. Franklinite, tephroite, pyroxene, and biotite compose the leanly mineralized areas. The mineral distribution is zoned. Black willemite with magnetic franklinite forms a band of varying thickness that follows closely the convolutions of the upper surface of the brown willemite, franklinite body. Ore textures are identical with those of the areas of lean mineralization, and the transition is not sharply defined. A thin band of rhodonite is found at this boundary between pyroxenes and willemite.

The rock core of the ore body is altered to zinciferous clayey mud, locally containing hemimorphite. This alteration extends from surface to a depth of 680 feet.

The variation in willemite color is due to color differences in <10 micron franklinite inclusions. Red franklinite is nonmagnetic with a unit-cell dimension of nearly 8.51 Å. Black franklinite is magnetic with a unit cell of about 8.42 Å. Macroscopic franklinite cell dimensions are intermediate. Origin of franklinite inclusions is attributed to willemite serpentinization, similar to that commonly observed in magnetite formation by serpentinization of olivine.

ISOTOPE GEOLOGY OF SOME LEAD ORES

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The isotopic composition of lead from galenas of several different ore bodies has been determined. A number of these deposits have relatively constant isotopic compositions. Nineteen samples from Central Peru covering a vertical range of almost a mile and distributed along a horizontal distance of 80 miles have a 206/204 ratio constant within 0.5 per cent. Similarly, a number of samples from several small mines surrounding the Boulder batholith in Montana show a range of only 1.5 per cent

in the 206/204 ratio. Four samples from the Sunshine Mine, Kellogg, Idaho, covering a vertical distance of 1000 feet and horizontal distance of 500 feet are constant within 0.6 per cent.

Model ages for the Peruvian and Montana samples are Paleozoic or later. The galenas from the Sunshine Mine give a model age of about 1400 m.y.

A group of samples from the Black Hills uplift indicate two distinct periods of mineralization; three samples indicate a Precambrian mineralization at about 1500 m.y., and five other samples suggest Paleozoic or later mineralization.

CHARACTERISTICS OF STREAMS IN THE SOUTHERN PORTION OF THE SANGRE DE CRISTO RANGE, NEW MEXICO

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Bankfull width and depth, channel slope, size, and lithologic composition of bed material were measured at 104 stations in the drainage basins of Rio Santa Barbara, Rio Santa Cruz, Pojoaque River, and Pecos River. Stream channels below junctions average two-thirds the sum of widths and half the sum of depths of the two tributaries. Downstream changes in width, depth, and velocity can be expressed as power functions of discharge, but exponents for Pojoaque River and Rio Santa Cruz are markedly different from values reported previously for streams at lower elevations. Mean particle size of bed material increases, decreases, or remains constant downstream in the various basins, and channel slope shows no relation to particle size. Through distances up to 80 miles, sorting and sphericity of bed material do not change. Granite and quartzite derived from particular outcrops show downstream size decrease proportional to distance traveled. Bed material at nearly all stations is much too coarse to be moved by bankfull velocities. The fact that recognizable particles from particular outcrops have moved means either that movement occurs during large floods or that much of the bed material is residual from a period of larger discharges during glaciation. No significant differences in channel characteristics occur on the various lithologies (sandstone, quartzite, granite, and limestone) present in the mountains, but both composition and size of bed material are closely related to local bedrock lithology. At the foot of the mountains where the unconsolidated Sante Fe Formation is encountered, channel width increases and size of bed material decreases abruptly.

MASS MOVEMENT AND STRESS RELATIONS IN THE TAKU GLACIER, ALASKA

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The prevalence of tectonic foliation and related fracture structures in marginal zones of the Taku Glacier suggests that discontinuous movements are an important factor in the mass transfer. The significance of this factor is emphasized by surface-velocity profiles which exhibit a Blockschollen form. In the central part of the glacier, however, uniform flow structures are found in core samples to a depth of at least 292 feet, indicating that the essential movement in the main body of ice is continuous. An exponential flow relationship is derived from a stress/strain analysis of the annual deformation of a 245-foot aluminum tube drilled into the ice. By extrapolating this empirical law to the mean seismic depths on selected transects comparisons are made between the proportion of movement within the glacier and that accorded to slippage on the bed. The results show that in the wastage area of the lower glacier from 55 to 92 per cent of the total movement is from basal sliding. This implies the existence of a strong longitudinal stress trajectory supplemental to the normal shear component of flow and probably related to the persistent advance of this glacier since the 1890's.

Volume-transfer calculations indicate that 97 per cent of the material passing into the trunk

glacier near the névé line is supplied by tributaries from the crestal sector. Measurements of an excessively positive regime pertaining over the highest névés during the past 40 years corroborate the mass-movement computations and provide reasonable explanation of the composite stressing condition indicated by the flow data.

ALKALIC ROCKS ASSOCIATED WITH TRIASSIC DIABASE NEAR LAMBERTVILLE, NEW JERSEY

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Near Lambertville, New Jersey, between an indurated black Triassic shale of Lockatong age and a large body of diabase is a zone several hundred feet thick of quartz-bearing diabase, in which is found alkalic rock of teschenitic aspect which Ransome in 1899 described as nepheline-, hornblende-, biotite-, quartz syenites, and hornblende granite. Present work on Ransome's original material and subsequent collections has not shown nepheline or cancrinite in these rocks; it is believed that sanidine may have been mistaken for nepheline, and muscovite for cancrinite.

The teschenitic rock typically contains abundant brown hornblende, brown biotite, sanidine, sodic plagioclase, analcite, and minor apatite. Hornblende and biotite vary greatly in abundance in single specimens. The upper levels of the diabase sill contain considerable micrographic quartz-feldspar ("quartz-syenite"—Ransome), and gradation from normal diabase through this siliceous phase into the teschenitic rocks is observed. There has been strong reaction with black shale locally to produce hybrid rocks. It is suggested that whereas ordinary diabase tends to solidify rapidly over a small temperature range, producing scanty contact effects, the siliceous quartz-feldspar upper differentiate solidifies over a considerable temperature range and can cause marked assimilation and alteration of enclosing rock, as well as deuteric effects in the contiguous solid diabase. Thus, alkalic rocks of teschenitic aspect may be looked for as normally accompanying large bodies of diabase in which considerable micrographic quartz-feldspar differentiate has accumulated and has reacted with presumably calcareous country rock causing desilication.

BISMUTOFERRITE, CHAPMANITE, AND "HYPOCHLORITE"

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Bismutoferrite, $Bi(OH)Fe_2(SiO_4)_2$ or $Bi_2O_3 \cdot 2Fe_2O_3 \cdot 4SiO_2 \cdot H_2O$ (in substantial agreement with Frenzel's, 1871, $Bi_2Fe_4Si_4O_{17}$), occurs as a yellow powder associated with bismuth ores at Schneeberg, Saxony, and near-by localities and gives a unique X-ray diffraction pattern and consistent chemical analyses. It is therefore to be considered a valid mineral species. The term "hypochlorite" has been used for a green mixture of bismutoferrite with quartz and chalcedony. The original analysis in 1832 was of such material; the first analysis of reasonably pure bismutoferrite was by Frenzel in 1871. At Bräunsdorf, Saxony, a substance was found that was also termed "hypochlorite", but which contains antimony instead of bismuth. Recognition of the composite character of "hypochlorite" and uncertainty as to whether it contained bismuth or antimony or both, with failure to accept Frenzel's work as valid, has until now left the status of bismutoferrite and "hypochlorite" dubious. Data presented here establish chapmanite (Walker, 1924) as the antimony analogue of bismutoferrite. Recognition of the proper valence states of antimony and iron (both trivalent) in chapmanite leads to a correct interpretation of the formula from the original analysis. Bismutoferrite and chapmanite therefore form a homologous and presumably isostructural group of two valid species; the name "hypochlorite", which has been used to designate a characteristic mixture of either of these minerals dispersed in quartz or chalcedony, may well be discarded.

ORGANICALLY DERIVED GASES AS A CONTROLLING FACTOR IN SUBAQUEOUS SLUMPING

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Evidences of subaqueous slumping include intrastratal crumpling, spiral rolls, isolated sand rolls, injection sandstone dikes, and bedding slip planes.

In seeking to reproduce these structures experimentally, it was found that slumping of sediment standing at less than its angle of repose occurs when the interstitial fluid is saturated with gas. Conversely, the same artificial accumulation of sediment stood firm when the interstitial liquid was not charged with gas.

In nature, most structures due to slumping are confined to beds in and near which large quantities of organic material were deposited. During and prior to diagenesis, hydrogen sulfide and methane are presumably liberated and become dissolved to saturation in the interstitial water. Even for sediments deposited on slopes of 2°, agitation by earthquakes should cause this gas to leave solution, forcing grains apart, and diminishing the strength of the sediment to the point that slumping takes place. In all probability it is this gas that causes sand to flow, roll into balls, and be injected into clays as clastic dikes.

If indeed the presence or absence of interstitial gas is a critical factor in slumping, it follows that the deposition and burial of much organic material under euxinic conditions affords one of the most favorable enviromnents for these mass movements of sediments.

RADIOACTIVITY SURVEYS AND THEIR RELATION TO GEOLOGIC FEATURES, TEXAS COASTAL PLAIN

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An airborne radioactivity survey was made in the central Texas Coastal Plain uranium district and adjacent areas in 1956. Results indicate that the average equivalent uranium content of the Tertiary sediments ranges only from <0.001 to about 0.002 per cent; the radioactivity probably being an inherent characteristic of the stratigraphic units. Some units, particularly the sands, are uniformly low in radioactive content over tens of miles and are easily traced on the survey records.

In certain places, ranging from a few tens to several hundreds of square miles in area, anomalous areas stand out markedly on the radioactivity records although the increase in radioactivity is probably less than 20 ppm eU over the average content of the sediments. The radioactive character of the sediments in these areas has been modified either by addition of radioactive material or by the redistribution and concentration of original radioactive material. The principal ore deposits of the Karnes County district lie within the largest and most intense of these anomalous areas.

Within the largest anomalous area are localities of high-intensity gamma radiation indicating the location of ore deposits. The recorded magnitude of the high-intensity anomalies is far greater than predicted from theory considering the size of the ore deposits and results from radioactivity halos which enlarge the surface extent of the deposits. These halos partially surround the loci of mineralization and are not confined to the surficial material but extend downward into bedrock.

BRUNTON COMPASS DESENSITIZED TO GIVE DIRECTION OF MAGNETIZATION OF LATE CENOZOIC BASALTS, NORTHEASTERN NEW MEXICO*

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The direction of magnetization of weakly magnetized rocks can be determined by using the following procedure: Orient Brunton compass on pedestal (block of wood, glass). West (or east) of the pivot of the needle, place a magnet on pedestal with its north pole north. Move magnet in until it nearly cancels earth's magnetic field. Needle will swing slowly with wide arc. Rotate magnet until needle is again oriented.

On opposite side of compass, hold a rock sample level with needle and inches away. Rotate rock until north end of needle has maximum repulsion. In this position place finger horizontally along rock, pointing toward pivot of needle. The finger is now parallel with magnetic alinement of the rock, pointing toward its north pole. Now turn rock into its original field orientation. If finger points north and down, magnetization is normal (for Cenozoic rocks in northern hemisphere). If finger points south and up, magnetization is reversed.

The following groups of 117 oriented samples of basalt, from Union and Colfax counties, are coded by the number of samples of reversed, anomalous, and normal magnetization, respectively. Capulin age (Recent) basalts are 5-0-6; Folsom vent samples are 1-0-0. Basalts of late Clayton age are 4-0-0, and basalts of early Clayton age are 0-0-3. Clayton age flows of indeterminated position are: Van Cleve, 2-2-5, Gaps, 0-0-5; Clayton Mesa, 6-2-3; Carrizo, 8-0-10; and miscellaneous, 5-1-10. Younger to older basalts of Clayton to Raton(?) age in the Don Carlos Hills are 2-1-1, 0-0-3, 4-5-7, and 3-3-2. Raton age (Pliocene?) basalts are 1-2-5.

FILLED BEDROCK GORGES IN THE DRAINAGE BASIN OF CAYUGA LAKE, NEW YORK

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Filled bedrock gorges in the drainage basin of Cayuga Lake in central New York are deeper and broader than their present analogues which have been eroded since the Cary substage of Wisconsin glaciation. Accordingly the gorges are probably interglacial in origin and have been considered by previous investigators to be of probable Sangamon age.

Recent data from Pleistocene sections contained within the filled gorges show that (1) the interval of gorge cutting was followed by glaciation prior to 35,000 years ago, and (2) an interval of more than the past 35,000 years is represented by only a single till sheet.

In the valley of Six-Mile Creek near Ithaca, a single till sheet overlies proglacial lake sediments containing bits of wood dated as 35,000+ years old. About 25 miles north of Ithaca, in the Great Gully, lake deposits containing wood beyond the range of radiocarbon dating lie between till sheets which are closely similar, even to the point that each contains disseminated organic material eroded by the ice from a local pre-existing source within the Great Gully. Apparently, in this case the interval of gorge cutting was followed by accumulation of organic material in such position that it was subjected to erosion during each of two succeeding glaciations.

Existing data allow for postulation of a post-Sangamon glaciation older than the Farmdale of the Mid-Continent region to account for the sections exposed in the filled bedrock gorges of Cayuga drainage basin.

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* Publication authorized by the Director, New Mexico Bureau of Mines and Mineral Resources.

MULTIPLE GLACIATION IN THE PUGET SOUND BASIN, WASHINGTON

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At least four glaciations are represented by four separate glacial drifts in the southeastern part of the Puget Sound basin. The oldest glacial drift overlies weathered Miocene(?) sediments with a slight angular unconformity. The lithology of the drifts shows that ice advanced southward from British Columbia rather than westward from the local Cascade Range. Radiocarbon analyses indicate that the latest glaciation, the Vashon, is early Wisconsin; the three earlier glaciations are thought to be pre-Wisconsin.

The Vashon drift is separated from older glacial drift by an unconformity, which probably represents the time during which the major topographic forms of the basin were developed. The three older drifts are separated from each other by unconformities and by sediments containing pollen that indicate a nonglacial, possibly interglacial climate; thus each drift may represent a separate stage. The three pre-Vashon drifts each contain two till sheets, separated by locally derived lacustrine and fluvial sediments. These till sheets probably indicate retreat and readvance of the same glacier, but may represent different glaciations.

Depth of weathering in the pre-Wisconsin drifts is not proportional to age, probably because of rapid burial by nonglacial sediments.

Correlation of the pre-Wisconsin Puget Sound glaciations with the pre Wisconsin glacial stages of midwestern United States cannot be made with any certainty at this time.

EXPERIMENTAL STUDY OF THE ZIRCON-THORITE GROUP

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An experimental study has been made of the system ZrO_2-ThO_2-SiO_2-H_2O at temperatures up to 1200°C. and at pressures up to 4000 atmospheres. The limit of solid solution between $ZrSiO_4$ and $ThSiO_4$ is approximately 5 mole per cent in the thorite structure and less than 3 mole per cent in zircon at about 800°C. and 1500 atmospheres. Metastable solid solutions could be prepared at lower temperatures with up to approximately 25 mole per cent $ZrSiO_4$ in thorite and about 35 mole per cent $ThSiO_4$ in zircon.

Huttonite can easily be prepared dry and hydrothermally from gels at all temperatures above 1100°C. and is also obtained hydrothermally at temperatures as low as 400°C. in the join $ZrSiO_4$-$ThSiO_4$. Evidence bearing on the possibility that huttonite is the only stable polymorph of $ThSiO_4$ is presented.

No evidence supporting the existence of a solid solution between $ZrSiO_4$ and "$Zr(OH)_4$", involving the so-called $(OH)_4^{-4}$ substitution for SiO_4^{-4}, has been found. Mixtures on this join yielded ZrO_2 plus zircon at all temperatures from 250°C. to 900°C. at 3000 atmospheres or less.

From 1000°C. to 400°C. at all pressures studied there is less than 2 mole per cent solid solution at either end of the system ZrO_2-ThO_2, in agreement with natural analyses of baddeleyite and thorianite. At lower temperatures, however, a complete metastable series of solid solutions, having the cubic fluorite structure, can be formed.

AMOUNT AND DISTRIBUTION OF THORIUM, URANIUM, AND POTASSIUM IN SANDSTONES

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Thorium, uranium, and potassium concentrations were obtained for more than 20 sands and sandstones by means of gamma-ray spectrometry, fluorometric uranium determinations, and alpha

counting. Heavy-mineral separations were made on several of these to see how much the heavy detrital minerals contributed to the total radioactivity of the sands. Autoradiographic studies were done on a number of samples of both the quartz and the heavy-mineral fractions in an effort to locate the exact loci of the thorium and uranium series. The sands chosen for the study were selected so that common and possible extreme thorium and uranium concentrations would be represented.

The average and nearly uniform content of these three elements in orthoquartzitic sands is: potassium (as metal) 0.64 ± 0.04 per cent, thorium 1.75 ± 0.1 ppm, and uranium 0.45 ± 0.05 ppm, giving a Th/U ratio of 3.9 ± 0.8. This ratio is within the range for average igneous rocks and may represent an independent determination of the average crustal thorium/uranium ratio. The radioactivity of the common sandstones studied is contained almost entirely in the quartz, where it appears to be related in large measure to microscopic and submicroscopic inclusions within the quartz. The heavy detrital minerals do not begin to affect the thorium/uranium ratio or concentration levels until they occur in large quantities as in placer sands.

These preliminary data are helpful in constructing models of the changes in thorium and uranium concentrations that may be observed in moving from the beach through shallow-water sediments to deep-water sediments.

SOME RELATIONSHIPS OF GEOLOGIC TEACHING AND RESEARCH

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Instruction of undergraduate students in geology involves the impartation of (1) historical information pertaining to the science, (2) current ideas and facts, and (3) knowledge of how to apply this information or how to do things. Graduate education places emphasis on research, an essential part of the overall program being the seminar, and requires a considerably greater degree of specialization and experience on the part of the instructor. As the majority of all these students are trained for the practice of a profession rather than for ivory-tower positions, it is mandatory that instructors be competent in all phases of geology.

Broadly speaking, geologic research is any effort which develops or contributes knowledge to the discipline and, therefore, to the various aspects of teaching. Familiarity with literature and texts may permit excellence of instruction in certain survey and factual-data courses, but it cannot develop the competence or specialization which is achieved through research experience, applied or otherwise.

A poll of 2200 graduate students at Louisiana State University in 1950–1951 categorized 65 professors in widely separated fields as best teachers. Forty-six per cent of these men possessed a record of continued productivity in scholarship and research; another 16 per cent showed occasional productivity; 67 per cent of the selected group had research in progress as against only 40 per cent of the faculty as a whole, including the best teachers. These statistics imply that productive researchers are more likely to be good teachers than colleagues who are less active in research.

REVISION OF THE DEVONIAN STRATIGRAPHY IN EASTERN VERMONT

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The Devonian rocks between the Northfield Slate and the Gile Mountain Formation in the Barre-East Barre area in Vermont can be distinctly divided into three lithologic units on the basis of their mappability. The western two units are continuous with the Barton River and Westmore formations from the type area in the Memphramagog quadrangle. Hitherto, these two units were included with the unit of calcareous rocks in the central part of the East Barre quadrangle in the all-too-comprehensive "Waits River Formation".

An analysis of minor folds and cleavage-bedding relations in the area indicate the possibility of

correlating the Westmore with the Gile Mountain Formation, across the limbs of a major syncline, the trough of which is occupied by the calcareous unit in the central part of the East Barre quadrangle. If correct, this interpretation makes the calcareous unit the youngest in the Vermont sequence and hence calls for a revision of the stratigraphic sequence in eastern Vermont.

The writer considers it advisable to redefine the old Waits River Formation in such a way as to distinguish between the eastern and western calcareous units.

SEISMIC-REFRACTION MEASUREMENTS AND SEDIMENTS OF THE BLAKE PLATEAU, SOUTHWEST ATLANTIC OCEAN

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The Blake Plateau is a region of intermediate water depth (300–700 fathoms) bounded on the south by the Bahama Platform and on the west by the coastal shelf of Florida and Georgia. On its eastern side the Blake Plateau is bounded by a steep escarpment along which the water depth increases abruptly to 2650 fathoms. The present paper presents results of seismic-refraction investigations, topographic data, and analysis of sediment cores for stations in the southern half of the plateau.

Seismic-refraction measurements are combined to give two seismic sections, one parallel to the coast of Florida on the western margin of the plateau, and one on an east-west section across its southern half.

The prominent interfaces found by seismic refraction are compared with the marked changes of slope of the eastern escarpment observed by sonic depth recording. These interfaces crop out on the escarpment at water depths of approximately 700–900 and 1200–1400 fathoms. Cores from the neighborhood of the escarpment have been examined and dated by means of microfossils. These range in age from Early Cretaceous to Miocene. It is demonstrated to be feasible to use data from cores, seismic refraction, and topography to effect a rough correlation between the lithologic section at the escarpment and those of wells of the Florida coast and Andros Island.

CARBONATE FACIES AND BIOTIC COMMUNITIES OF NORTHWESTERN GREAT BAHAMA BANK

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Studies of the northwestern Great Bahama Bank from 1955 to 1957 have included systematic sampling and mapping of bottom facies north of the latitude of Orange Cay. Major bottom types are rock, sand, and muddy bottom. Among these there are several subfacies characterized by distinctive grain type and biotic community.

At each of 90 stations sediment samples were taken, direct observations of the bottom made, and benthic organisms collected by dredging and by sieving unwashed Van Veen grab samples.

The facies distributions indicate that the trade winds have a marked effect on Bank environments. Coral reefs are restricted to the windward margin, and mud deposition is almost limited to the lee side of Andros Island. Influence of depth and turbulence is especially marked near the margin where rock facies and oölitic sand roughly follow depth contours.

The extent of calcareous mud west of Andros is smaller than reported. Most of the fine sediment lies within the Island in swamps and estuaries rather than on the Bank. Marked diversity in occurrences of the mud precludes any simple explanation of its origin.

Oölitic sand of the region shows fresh accretion and high luster in areas repeatedly exposed to the air. Dull grains, characteristic of deeper water, are judged to have been transported from inter-

tidal areas or were formed at a lower level of the sea. The probable importance of oölite as an indication of former sea levels is stressed.

MICROFAUNA OF THE UPPER CRETACEOUS NAVESINK FORMATION IN NEW JERSEY

Ogden Nine
Arabian American Oil Company

Throughout the area from Atlantic Highlands to the New Egypt region, New Jersey, in the central part of the Coastal Plain the foraminiferal and ostracod faunas of the Navesink are large and diversified with an abundance of planktonic Foraminifera. The association of these assemblages with much glauconite indicates optimum neritic conditions and reveals that the Navesink represents the maximum transgression of Late Cretaceous time in New Jersey.

The Navesink is correlated with the upper Navarro of the Gulf Coast. Seventy-eight species of Foraminifera found in the Navesink occur in Gulf Coast formations. Of these, 73 are known from the Navarro; 31 species are restricted to the Navarro. Of the 31 restricted Navarro forms, half are known only from the upper Navarro.

SOME NEW SPECIES OF MIOCENE FAUNA FROM MARYLAND

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Extensive examination of Middle Miocene deposits of Maryland and New Jersey has revealed several new species of the already well-represented genus of *Turritella*. Additional new representatives of other genera have been noted.

A comprehensive exhibit of Miocene fauna from the Kirkwood Formation outcropping in southern New Jersey; from the lower part of the Calvert Formation in Randle Cliff and Plum Point in Maryland; from the upper part of the Calvert (Choptank) Formation in Calvert Cliffs in Maryland; and from the St. Mary's Formation in St. Mary's City, Chancellor Point in Maryland, has been prepared and is available to show the faunal assemblage which includes the new species.

VALIDITY OF RADIOCARBON DATES ON ORGANIC SAMPLES WITH AGES GREATER THAN 25,000 YEARS

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The radiocarbon ages of samples older than 25,000 years are very sensitive to small amounts of recent carbonaceous contamination. For organic materials potential contamination is generally of two types: (1) permeation of ground-water-transported microscopic organic compounds commonly called humic acids, and (2) intrusion of macroscopic animal or plant materials such as rootlets. Since it is possible to isolate chemically the humic acid contaminants into a single organic fraction (lignin), one can spotlight any humic contamination by dating more than one fraction (*i.e.*, lignin and cellulose). The second type of contamination is best handled by careful sample selection and mechanical cleanup. One way to detect any type of contamination is to date contemporaneous samples of a different nature, such as wood and peat.

Samples for such a program were selected with two criteria in mind: (1) samples with ages in the 25,000 to 50,000 year age range, and (2) samples which had definite geologic significance. The samples which seemed to best fit both categories were organic deposits from beneath the tills of the major late Wisconsin glaciers. The dates of such deposits indicate periods of deglaciation in the

areas of interest as well as maximum dates for the time of invasion of the glaciers of the late Wisconsin. Two such deposits have been dated; the data are summarized as follows:

Material	Fraction	Age	
		Missinaibi River Sequence	Vancouver Island Sequence
wood	lignin	38,900 ± 2200	25,850 ± 500
	cellulose	38,600 ± 1800	25,900 ± 300
peat	lignin	38,600 ± 1700	24,650 ± 300
	cellulose	37,700 ± 1600	23,200 ± 600

LATE CRETACEOUS AND EARLY TERTIARY STRATIGRAPHY OF NEW JERSEY

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Analysis of the Late Cretaceous Redbank and Tinton formations and the Early Tertiary Hornerstown Formation reveals several distinct foraminiferal assemblages.

The Redbank and Tinton foraminiferal faunas consist of typical Late Cretaceous species and forms such as *Globorotalia* heretofore known only from beds of Tertiary age. This suggests post-Navarroan pre-Tertiary age.

Three planktonic faunas are recognized in the Hornerstown Formation. The basal part of the Hornerstown carries distinctive planktonic Foraminifera that are present in the type Danian of Denmark and the lower Midway of the Gulf Coast. The middle fauna contains a planktonic assemblage typical of the upper Midway of Alabama. The uppermost part of the Hornerstown carries a large and varied benthonic fauna which contains a number of forms in common with the Midway of the Gulf Coast and some Eocene elements. It also contains many species that are present in the Vincentown, Salt Mountain, and Aquia formations. However, the planktonic fauna of the uppermost part of the Hornerstown lacks the diagnostic upper Midway species and contains other forms not present in the Midway. This fauna may represent the basal Eocene (nonmarine Sparnacian of Europe).

Studies of surface and well sediments, substantiated by faunal evidence, indicate that the Redbank and Tinton formations are present in southwestern New Jersey. The Hornerstown Formation lies unconformably upon the Tinton throughout New Jersey Coastal Plain.

ANALYTICAL PROCEDURES APPLICABLE TO FINE-GRAINED SEDIMENTARY ROCKS

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Several thousand samples of shales and lignites have been analyzed chemically by a variety of methods. These include wet-chemical, radiometric, flame-photometric, and absorption, emission, and fluorescent X-ray spectroscopic procedures. The chemical constitutents determined include Si, Al, Fe, Ca, Mg, Sr, Ba, K, Na, P, U, V, Cr, Mn, Ni, Co, S, C, and H.

The complex nature of the sediments and the need for determination of trace elements, as well as major constituents, has necessitated the modification of existing methods and the development of new ones.

This paper summarizes those analytical methods found to be best suited to the evaluation of a large number of constituents in fine-grained rocks and points out the limits of precision and accuracy that may be expected.

APPLICATION OF PUNCHED-CARD ANALYSIS TO LIMESTONE EXPLORATION

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A comprehensive analysis of field and laboratory data was made, using IBM punched cards, to determine the relationship between chemical composition and the geological position and geographical location of a limestone.

For each of more than 600 samples, the sample number, chemical analysis consisting of percentages of CaO, MgO, SiO_2, R_2O_3, loss, total, $CaCO_3$, and $MgCO_3$, stratigraphic position, structural distribution, and field traverse section were recorded on an IBM punched card. The MgO/CaO ratio was calculated for each sample using an IBM calculating punch machine to perform and check the computation. Sequence numbers were assigned to place the chemical composition of the samples in relation to each other for MgO, CaO, a combination of high CaO, progressively lower MgO, SiO_2, R_2O_3, and a combination of high CaO, progressively lower SiO_2, MgO, R_2O_3; machines sorted the cards and assigned and recorded the sequence numbers.

Printed lists, prepared by machine, show the data arranged by sample number and the frequency distribution of MgO in relation to each of the chemical components to stratigraphic position, to structural distribution, and to the field traverse section.

With the exception of planning procedures, these operations took about a week of operator and machine time. Thus, in a short period all the available data were analyzed and prepared in a form for visual inspection or use in preparing maps that show the location of the areas containing the desired quality of limestone.

CENSUS OF WOMEN GEOLOGISTS

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A survey of the membership lists of AAPG, GSA, and SEPM shows that about 1 per cent of AAPG and 3 per cent of GSA and SEPM members are women. From these and other sources a list of more than 300 women in geology has been compiled.

Women are associated with three types of organizations—industry, government, and universities and museums—in about equal numbers. The professional activities of the women are summarized as an indication of the fields of geology for which students may prepare themselves most profitably.

POCONO PALEOCURRENTS

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The Pocono (Mississippian) of Pennsylvania and Maryland was studied in order to reconstruct paleocurrents, source area, and paleogeography of Pocono time. Thickness, lithofacies, current structures, oriented plant remains, and distribution of plants, marine faunas, and pebble sizes were investigated.

Five thousand cross-bedding attitudes were measured at more than 200 localities. Direction of sedimentary transport shown by cross-bedding was northwesterly. The paleoslope, reconstructed by contouring the moving average of the mean of the greatest diameters of the 10 largest quartz pebbles at each locality, dipped northwestward across Maryland and Pennsylvania.

Tilt-corrected strikes of more than 300 oriented plants were plotted for the anthracite region, Pennsylvania. They lay perpendicular to the regional current direction generally.

Extrapolation of size-distance curve of pebble diameters gave an estimated position of the source area. The position was near Atlantic City, New Jersey.

Stratigraphic and petrographic analyses, the paleocurrent pattern, and numerous current structures indicated that Pocono was fluviatile and that the source area was a belt of clastic and low-rank metamorphic rocks.

Upper Devonian, Mississippian Mauch Chunk, and Lower Pennsylvanian strata were examined at 35 localities. Cross-bedding measurements indicated current directions similar to those of the Pocono.

Extrapolation of the Pottsville (Pennsylvanian) size-distance curve of pebble diameters gave the estimated position of the Pottsville source area, as near Philadelphia, about 100 miles northwest of the Pocono source area, indicating migration of source area to the northwest.

CHROMITE IN THE ZAMBALES RANGE, LUZON

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From the Zambales Range on the western flank of Luzon Island has come in recent years most of the refractory chromite of the world and a substantial amount of metallurgical chromite. Mapping in the northern part of the range has delineated alternating belts of ultramafic and layered gabbroic rocks that trend east of north diagonally across the range. The western ultramafic belt contains several tabular chromite deposits, chiefly of the metallurgical type. The major refractory chromite deposits are in an ultramafic rock belt bordered on both sides by layered gabbroic rocks.

Exploration being carried on by the Philippine Bureau of Mines with the co-operation of the International Cooperation Administration, on a government mineral reservation, has already proved a substantial tonnage of good-grade refractory ore. The ore body lies on the line of strike and is 1000 meters north of the famous Coto ore body on Masinloc.

Both the metallurgical and refractory chromite deposits are associated with layered dunite and saxonite; however, layering is far better developed near the metallurgical ore than near the refractory. The two types of ores differ in texture and in alteration of associated silicates, as well as in composition. Dioritic and gabbroic dikes are abundant near refractory deposits and absent near metallurgical deposits.

OCCURRENCE OF RHENIUM, ASSOCIATED WITH URANINITE, IN COCONINO COUNTY, ARIZONA

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Twenty-nine samples of sedimentary rocks of Triassic age from the Sun Valley uranium mine in northern Arizona were analyzed spectrographically, and 11 of these samples contained from about 0.005 to 0.1 per cent of the rare metallic element, rhenium.

The rhenium is genetically associated with the uranium and molybdenum (and probably the cadmium, lead, and zinc) in the mine and was found to be in the form of the water-soluble oxide (Re_2O_8) or the perrhenic acid ($HReO_4$). The association of the water-soluble molybdenum mineral, ilsemannite, with the rhenium oxide indicates that the rhenium may have been contained originally in the mineral jordisite.

The Sun Valley mine is the only uranium deposit on the Colorado Plateau known to contain rhenium.

RECENT HISTORY OF CANWELL AND CASTNER GLACIERS, ALASKA

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The Delta River valley in the central Alaska Range displays evidence of two advances of Canwell and Castner glaciers within the last 300 or 400 years. The end moraines of the earlier advance are fragmentary; they are largely forested, covered with turf, and bear lichen-covered boulders. During the later advance, the glaciers fell short of the earlier advance by about half a mile. The moraines of the later advance look fresh, have few trees and no turf, and bear boulders on which lichen growth is scant or lacking.

The advances cannot be dated precisely by the age of trees growing on the moraines because, owing to strong winds and near-timber-line altitude (2500 feet), trees may not become established for 30 to 50 years. The 1937 moraine of near by Black Rapids Glacier remains treeless after 20 years. On the earlier moraines, tree ring counts indicate that the oldest trees (except for rotten-centered spruce estimated to be 200 to 250 years old) are 155- to 165-year-old spruce. A spruce log from the till of the older end moraine of Canwell Glacier was determined to be less than 200 years old by radiocarbon dating (W-268). Trees on the later moraines are 100 to 140 years old.

Black Rapids glacier, 10 miles northwest, has a similar record, and study of aerial photographs suggests that many glaciers in the central Alaska Range have had advances correlative with those of Canwell and Castner glaciers.

ROCK CHARACTERISTICS AT PAULO AFONSO HYDROELECTRIC DEVELOPMENT, BRAZIL

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The Paulo Afonso Hydroelectric Development, located on the lower Sao Francisco River near the corners of the states of Alagoas, Pernambuco, and Bahia in Brazil, has an unusual powerhouse design; it is underground in rock. The design was determined by topographic and hydraulic characteristics of the Paulo Afonso waterfalls and not for economic or national defense reasons.

The project consists of a gravity dam 4230 m. long above the waterfalls; an underground powerhouse 60.15 m. long, 15 m. wide, and 31.34 m. high; and a tailrace tunnel 10 m. in diameter and 180.25 m. long. Sixty-five thousand cubic m. of rock was excavated.

Site investigations were started in 1946, and the first unit was placed in commercial operation in 1954.

Since this was the first underground powerhouse in Brazil, extensive tests were made on laboratory samples and on the rock in place. The bedrock consists of a crystalline complex of Precambrian migmatite, pegmatite, and aplite with some minor fault zones. Two Huggenberger deformation and two strain-gage tests indicated that the rock was in considerable stress in certain directions. A maximum deformation of 0.007 inch was recorded in the vertical direction, whereas the minimum, corresponding to the horizontal direction, was slightly more than 0.001 inch.

Two hydraulic pressure tests, using a pressure of 16 kg/cm² and 12 kg/cm², were made in horizontal and vertical test chambers. These tests indicated that the rock had a modulus of elasticity between 150,000 and 300,000 kg/cm, and 200,000 kg/cm was adopted in the design.

GEOLOGIC ASPECTS OF THE 1956 LANDSLIDES AT SANTOS, BRAZIL

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Unusually heavy rain storms, 954 mm rainfall, in March 1956 caused numerous, large, highly destructive landslides in and near Santos, Brazil's largest seaport. These slides caused more than

100 deaths and several million dollars damage to property. An engineering and geologic study was made to determine some of the causes as well as measures to reduce future slides.

The larger slides ranged in volume of material from 1500 to 4000 cubic meters, and one large slide temporarily blocked a stream, so that flood waters added to the damage.

The steep, dome-shaped hills composed of residual soil, granites, gneisses, and schists, attain a maximum elevation of 210 m above sea level. Most slopes of 45° or less are covered by residual soil and dense vegetation, but those steeper than 45° are devoid of soil. The tendency of exfoliation regardless of the rock types on the hills caused some of the rock slides.

Some of the slides were aided by man-made excavations such as quarries, road cuts, trails, excavation for houses, and waste water. Future slides could be reduced by slope protection and surface and subsurface drainage.

Sr/Rb AGE STUDY OF TEKTITES

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Sr, Rb, radiogenic Sr contents, and Sr isotopic ratios were determined mass spectrometrically in eight tektites. K was determined flame photometrically. Results are reported below $\lambda\ Rb^{87} = 1.39\ 10^{-11}\ year^{-1}$.

MIT number	Name	K per cent	Rb ppm	Sr ppm	$^{87}Sr^*$ ppm	84/88 ±0.0003	86/88 ±0.005	87/86 ±0.003
3312	Indochinite	2.4	110	111	0.11	0.0068	0.1202	0.722
3309	Indochinite	2.5	126	.17	0.09	Not computed		0.720
24	Indochinite	—	110	120	0.16	Not computed		0.726
3313	Australite	2.4	111	141	0.32	0.0065	0.1197	0.735 ±0.010
3310	Australite	2.4	110	284	0.16	0.0070	0.1205	0.718
3311	Philippinite	2.7	141	150	0.11	0.0068	0.1196	0.719
23	Philippinite	—	108	162	0.24	0.0069	0.1195	0.727
3314	Moldavite	3.0	130	136	—	Not completed	—	—
Tertiary basalts (P. Gast, private communication) Rb/Sr ratio ~ 0.1								0.708
Sea water (Pinson, 1957)								0.711
Normal Sr (Nier, 1938)								0.712

Tektites, because of their small Rb/Sr ratios, are unfavorable samples for age determination. Large errors of about ±50 per cent accompany each computed age. If an initial 87/86 ratio of 0.712 is assumed, which is the ratio in present-day common Sr, the ages range from 180 to 730 m.y., with an average age of 380 m.y. If 0.710 is assumed, the ages are increased 20–30 per cent. However, tektites are an order of magnitude younger than chondrites and apparently significantly older than terrestrial volcanic glasses.

The very strong correlation in Rb contents and K contents and the small range in 87/86 ratios, when compared to analyses of randomly selected terrestrial rocks (*e.g.* obsidians), strongly suggests a common source origin for the tektites. No conclusion as to their terrestrial or extraterrestrial origin can be reached from these data alone, but they are contributory evidence for an extraterrestrial origin.

AGE STUDY OF SOME CRYSTALLINE ROCKS OF THE GEORGIA PIEDMONT

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Sr/Rb and A/K ages for micas extracted from Georgia rocks are as follows (B—biotite; M—muscovite):

M.I.T. number	*Name, location*	*A/K age (m.y.)*	*K per cent*	*Sr/Rb age*	*Rb ppm*	*Sr ppm*	*Radiogenic Sr^{87}*	Rb_B/Rb_M
B26	Stone Mountain Granite			280 ± 14	1160	7.2	1.3	
B260	Stone Mountain Granite composite			297 ± 15	1104	7.1	1.3	
B3172	Stone Mountain Granite			283 ± 14	1127	10.3	1.3	
M3172	Stone Mountain Granite			272 ± 30	654	45.9	0.71	1.72
B3173	Panola Granite	360 ± 15	6.8	293 ± 15	723	30.2	0.83	
M3173	Panola Granite			313 ± 47	430	51.6	0.53	1.68
B3174	Lithonia Gneiss	330 ± 20	4.2	287 ± 15	858	17.4	0.97	
M3174	Lithonia Gneiss	330 ± 20	7.4	288 ± 20	947	53.3	1.08	0.91
B3175	Carolina Gneiss			342 ± 34	390	2.7	0.52	
B3176	Ben Hill Granite			282 ± 14	740	54.7	0.82	
B3177	Elberton Granite	345 ± 20	6.4	254 ± 13	1300	9.9	1.3	
M3177	Elberton Granite			245 ± 13	745	32.0	0.72	1.74

($Rb^{87}\lambda_\beta = 1.39 \times 10^{-11}yr^{-1}$; $K^{40}\lambda_\beta = 4.72 \times 10^{-10}yr^{-1}$; $\lambda_e = 0.557 \times 10^{-10}yr^{-1}$, B.R. = 0.118).

Excluding Carolina Gneiss which is country rock, presumably structurally older than the granites, and excluding the analytically younger Elberton Granite, the average Sr/Rb age is 288 m.y., which suggests Devonian rather than late Paleozoic origin.

The ratios of Rb in biotite to Rb in muscovite are constant at 1.7 in these granites, whereas this ratio is 0.9 in the Lithonia gneiss micas. Field and laboratory studies of L. Herrmann (1954) indicate that the gneiss is a metamorphosed sediment, whereas the granites may be intrusive. This ratio may be useful in distinguishing between metamorphic and intrusive rocks in a given petrographic province.

Rb, Sr, Ca, AND K CONTENTS AND THE ISOTOPIC RELATIVE ABUNDANCES OF Ca AND Sr IN A SEA-WATER SAMPLE

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A surface sea-water sample collected at 66° 18′ W., 39° 01′ N., at temperature 76.5°F. has the composition shown below in ppm by weight. Sample specific gravity was 1.028. Analyses were by mass-spectrometric stable-isotope dilution. Sr, 7.2 ± 0.6; Rb, 0.115 ± 0.019; Ca, 393 ± 8; K, 398 ± 18. Relative isotopic abundances for the sea-water Ca and Sr are given below, with other determinations of Ca and Sr isotope ratios.

	42/40	43/40	44/40	48/40
This work	0.00674	0.00141	0.0221	0.00202
	±0.00010	0.00004	±0.0003	±0.00005
Nier (1938)	0.0066	0.00150	0.0213	0.00191
	±0.0002	±0.00004	±0.0007	±0.00006
Backus (1955, MIT thesis)	0.00676	0.00142	0.0219	0.00206
	±0.00006	±0.00002	±0.0004	±0.00006
	84/88	86/88	87/88	87/86
This work	0.0067	0.1189	0.0845	0.712
	±0.0001	±0.0003	±0.0001	
Nier (1938)	0.0068	0.1194	0.0850	0.712
Aldrich and Herzog (1952)	0.0070	0.1196	0.0852	0.712
Herzog *et al.* (1954)	0.0067	0.1201	0.0850	0.711

POSSIBLE NATURE OF DEEP OCEANIC CRUST

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A standard deep-oceanic section shows 5 km water, ½–1 km sediment, and 5 km "basalt," underlain by the M discontinuity. Compressional wave velocities for the "basalt" average 6.7 km/sec., which indicates probable densities of 2.9–3.0. Magnetic intensities over the flat ocean floor are much lower than would agree with 5 km of normal basalt. Yet xenoliths in basalt flows on oceanic islands consist only of basaltic or ultramafic rocks. Nothing else is known about the deep-oceanic crust.

Yoder and Tilley found that at 1125°C. and 5000 bars water pressure, basaltic melt quenches to hornblende instead of glass. At 750°C. and 5000 bars, the melt crystallizes to plagioclase and hornblende.

It is suggested that the deep-oceanic crust is of basaltic composition but consists of plagioclase and a hydrous ferromagnesian mineral (amphibole or chlorite), with little or no magnetite. This would account for the high compressional velocities and low magnetic intensities. Xenoliths of this material in basaltic magma nearer sea level would lose water and recrystallize to typical basaltic rocks (dolerites or gabbros).

TEST OF THE HALF-LIFE OF Rb^{87}

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Sr/Rb analyses employing stable-isotope-dilution techniques were made on five minerals from the Spinelli Quarry and Strickland Quarry pegmatites. These pegmatites have been dated by Nier, Rodgers, and Wasserburg and Hayden, using radiogenic lead methods. The published ages are as follows: for the Spinelli Quarry, the Pb^{206}/U^{238}, Pb^{207}/U^{235}, Pb^{208}/Th^{232}, and Pb^{206}/Pb^{207} ages are, respectively, 253 × 10^6 yr., 255 × 10^6 yr., 266 × 10^6 yr., and 280 × 10^6 yr.; for the Strickland Quarry, the Pb^{206}/U^{238}, Pb^{207}/Th^{235}, and Pb^{208}/Th^{232} ages are, respectively, 268 × 10^6 yr., 266 × 10^6 yr., and 239 × 10^6 yr. By assuming the average concordant age for each pegmatite as the true age of its minerals, a resultant half-life of Rb^{87} was calculated for each mineral. These results are presented below:

Location	Mineral	Normal Sr (ppm)	*Sr^{87} (ppm)	Total Rb (ppm)	T½† (× 10^{10} yr.)	T½‡ (× 10^{10} yr.)
Spinelli Quarry, Conn.	Muscovite	9.36	2.79	2732	5.0 (±.3)	5.1 (±.3)
	Microcline	11.2	2.46	219	4.5 (±.2)	4.6 (±.2)
Strickland Quarry, Conn.	Muscovite	3.64	1.31	1256	4.9 (±.2)	—
	Lepidolite	9.71	9.84	7535	5.4 (±.3)	—
	Microcline	29.8	1.05	992	4.8 (±.3)	—

* Sr^{87} = radiogenic Sr^{87}.

† Based on average of Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{208}/Th^{232} ages.

‡ Based on average of Pb^{206}/U^{238}, Pb^{207}/U^{235}, Pb^{208}/Th^{232}, and Pb^{206}/Pb^{207} ages.

The average half-life based on the Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{208}/Th^{232} ages is 4.9×10^{10} yr.; the average half-life based on the Pb^{206}/U^{238}, Pb^{207}/U^{235} Pb^{208}/Th^{232}, and Pb^{206}/Pb^{207} ages is 4.8×10^{10} yr. Aldrich of the Carnegie Institution of Washington, using a similar method on six pegmatites of various geologic ages, reported a half-life of 5.0×10^{10} yr.

ALGAL DISINTEGRATION OF BAHAMIAN LIMESTONE COASTS

Edward G. Purdy and Louis S. Kornicker
Columbia University, New York, N. Y.

Algal-stained rocks of Bahamian coasts are characterized by small, irregular patches of unstained limestone freshly exposed by the removal of thin flakes of the surface rock. An investigation of this phenomenon shows that the outer algal-stained film of limestone is greatly weakened by boring algae, and it is this part of the rock that scales away, forming the white patches. It is becoming increasingly apparent that boring blue-green algae are among the most important agents of destruction of coast limestone.

RANK OF COAL AND METAMORPHIC GRADE OF ROCKS OF THE NARRAGANSETT BASIN OF RHODE ISLAND

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Brown University, Providence, R. I. and U. S. Geological Survey; Illinois State Geological Survey, Urbana, Ill.

The coal and the associated sedimentary rocks of the Narragansett Basin are progressively metamorphosed from north to south and southwest. X-ray analysis seems to give more definite indication of rank of these high-ash high-rank coals than does chemical analysis.

Both chemical analysis and X-ray analysis reveal a close correspondence between rank of coal and metamorphic grade of associated rocks. At Pawtucket, coal judged on the basis of X-ray analysis to be anthracite is associated with rocks of the muscovite-chlorite subfacies of the greenschist facies that contain muscovite, paragonite, and chlorite. At Portsmouth, meta-anthracite is associated with rocks still in the muscovite-chlorite subfacies and containing muscovite, chlorite, and ilmenite. At the Cranston Mine, higher-rank meta-anthracite is associated with rocks in the biotite-chlorite subfacies.

SOLUSPHERE, ITS SIGNIFICANCE AND STUDY

F. H. Rainwater and W. F. White
Water Resources Division, U. S. Geological Survey, Washington, D. C.

Water is a fundamental geologic agent active in rock decomposition, erosion, and synthesis. Solutes in water are of particular interest to geochemists as sources of raw material for synthesis or as products of decomposition. When geochemical studies move from the laboratory into natural environment many variables relating to solute hydrology must be considered.

As a focal point there has been designed a graphical representation of solute hydrology, the solusphere, which embodies the concepts of land-water occurrence and movement on which are superimposed geologic, biologic, physical, chemical, and cultural processes affecting solutes. The solusphere is demonstrated by passing an imaginary plane through the center of the earth. This plane intercepts concentric zones designated as rock flowage, saturation, aeration, surface activity, and atmosphere. Transport processes carry solutes within and between zones without alteration or conversion. However, whether stationary or in motion, the water's solute character is constantly subject to (1) alteration processes that change concentration by addition or subtraction of solutes or solvent without loss of solute identities, and (2) conversion processes that change the chemical state and form of solutes.

The geochemist is concerned with specific conversion processes, but he also must consider transport, alteration, and other conversion processes that are continually modifying the materials with which he is dealing in nature. The solusphere is an attempt to organize processes affecting the chemical quality of land waters into a unified field of science much like the field of marine chemistry.

GEOLOGY OF THE MOUNT MCKINLEY QUADRANGLE, ALASKA*

John C. Reed, Jr.
U. S. Geological Survey, Washington, D. C.

A reconnaissance geologic map of the Mount McKinley quadrangle at a scale of 1/250,000 has recently been compiled. Photogeologic techniques were used extensively to supplement field information.

Predominant structural trends in the quadrangle are northeasterly, parallel to the axis of the Alaska Range synclinorium. North of the range, Precambrian schists crop out over wide areas. Along the northern flank of the mountains is a belt of sedimentary rocks of Paleozoic age (mainly graywacke, argillite, chert, and limestone) overlain by spilitic greenstone of Triassic age and by continental clastic and associated volcanic rocks of the Cantwell Formation (Cretaceous). In the Alaska Range, south of the Paleozoic belt, is a little known series of slates and graywackes of Mesozoic age. Tertiary gravels occupy structural depressions in the mountains and probably underlie large areas to the north.

Discordant granitic plutons, some of batholithic dimensions, cut the Paleozoic and Mesozoic rocks. Some of these intrusives are pre-Cantwell. Others may be as young as Tertiary. Folds in the Alaska Range are commonly overturned to the north, but there is apparently no major overthrusting. A series of steeply dipping normal faults parallels the axis of the range.

Surficial deposits cover a large part of the quadrangle. They include moraines of several major glacial advances and associated outwash and eolian deposits. These have been mapped primarily on the basis of photogeologic studies. Criteria used in differentiating surficial deposits are described.

MINERAL ASSOCIATIONS IN THE GREEN RIVER FORMATION, WESTVACO, WYOMING

Andrew J. Regis and L. B. Sand
Department of Mineralogy, University of Utah, Salt Lake City, Utah

A study was made of the mineral associations in the Green River Formation at Westvaco, Wyoming to (1) help determine the paragenesis of the carbonate and silicate minerals, and (2) evaluate the effects of this chemical environment on the lake sediments.

Mineral associations found were: (1) loughlinite always has searlesite associated with it, but searlesite occurs without loughlinite; (2) dolomite decreases in amount where disseminated loughlinite occurs; (3) seams of fibrous loughlinite occur as replacements of dolomite-quartz layers, composed of alternating bands from ½ to 1½ inches thick of medium-grained dolomite and quartzite siltstone; (4) illite (little or no montmorillonite) is the dominant clay mineral associated with the seams of fibrous loughlinite; (5) montmorillonite is the dominant clay mineral associated with the carbonates; (6) considering the entire section studied, the bulk mineral composition in order of abundance is: quartz, calcite, dolomite, montmorillonite and illite, feldspar, shortite, searlesite, trona, and loughlinite; (7) pyrite, where occurring as veinlets, is associated with the carbonates.

The textural relations indicate that the formation of most of the minerals, other than the lake sediments, was by precipitation from the lake and by growth from the brines included in the shales. This latter crystallization probably was continuous during lithification.

Circulating ground water along quartz-dolomite layers produced seams of fibrous loughlinite, with associated tabular crystals of searlesite, and recrystallized some of the trona.

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* Publication authorized by the Director, U. S. Geological Survey.

TOPOGRAPHIC, GEOLOGIC, AND HYDROLOGIC FACTORS IN THE GAINESVILLE, FLORIDA, AREA AFFECTING SITE LOCATION FOR A NUCLEAR REACTOR

Stanley O. Reichert
Engineering and Industrial Experiment Station, University of Florida, Gainesville, Fla.

The topographic, geologic, hydrologic, and related engineering factors present in the greater Gainesville, Florida, area are described and illustrated in sufficient detail to provide an accurate picture of the site and surroundings for a proposed million-watt nuclear research reactor. This reactor should not be confused with the 10-kilowatt training reactor now being built on campus. The consequences of the accidental release of radioactivity from the reactor to the surrounding ground are considered in detail. The physico-chemical properties of the soil, subsoil, and bedrock are such that very little radioactive decontamination or adsorption can be expected. The soils are sandy and possess very little ion-exchange capacity. The bedrock is high-purity calcium carbonate possessing very little ion-exchange capacity and would react chemically only to neutralize acid radioactive solutions and precipitate insoluble carbonates. Because of the high porosity and permeability of the bedrock and abundant ground water close to the surface, any radioactivity released to the ground would spread rapidly through the Floridan aquifer and contaminate the entire Gainesville area water supply within 10 hours, as proven by a dye-stain test. It is concluded that, in order to reduce to an absolute minimum the remote possibility of discharge of radioactive liquid to the ground, containment must be provided. This conclusion is valid regardless of the location chosen in the Gainesville area. However, there are several areas off campus where there are natural safety advantages. These other areas are also evaluated in detail.

IDENTIFICATION OF ISLA SAN BENEDICTO, MEXICO, PUMICE ON ISLANDS IN THE CENTRAL PACIFIC OCEAN

Adrian F. Richards
Oceanography Division, U. S. N. Hydrographic Office, Washington, D. C.

Floating trachytic pumice originating from the 1952 eruption of Volcán Bárcena on Isla San Benedicto off the west coast of Mexico was collected on Hawaii, Wake, the Marshall Islands, and other islands in the Pacific Ocean. San Benedicto pumice was identified by color and vesicular texture, index of refraction of glass, and optical properties of phenocrysts—particularly index of refraction. X-ray-diffraction patterns of microphenocrysts also were used as an aid to identification. In order to determine and compare the mineralogical variability of drift pumices from other sources a study was made of pumice collected between 1951 and 1956 from widely different geographic localities in the north Pacific Ocean. San Benedicto pumice proved to be sufficiently distinctive compared to pumice originating from other sources so that chemical analyses were not necessary for identification.

A use for the identification of floating pumice, in addition to indicating source, is the computation of minimum drift rate when date of eruption and first appearance at islands is known. The computed rate of drift of San Benedicto pumice in the North Equatorial Current, over a distance of 4700 nautical miles to Wake Island and the Marshall Islands in about 560 days, is approximately 0.35 knots.

EFFECT OF HYDROSTATIC PRESSURE ON VELOCITY OF SHEAR DEFORMATION OF SINGLE ICE CRYSTALS

George P. Rigsby
1432 Carleton Square, San Diego 6, Calif.

Apparatus was built for the shear deformation of ice crystals under hydrostatic pressures in oil up to 350 atmospheres. Shear stresses were applied to single ice crystals in such a way that the

deformation readily occurred by gliding on the basal glide plane. The shear-strain rate was found to increase as the pressure was increased at constant temperature, but it was concluded that the shear-strain rate is practically independent of hydrostatic pressure when the difference between the ice temperature and the melting point is maintained at a constant interval.

CHANGING APPROACHES TO THE PROBLEM OF VERTEBRATE ORIGIN

George M. Robertson
Grinnell College, Grinnell, Iowa

Theories of vertebrate origin are largely morphological, with the same type of reasoning which has been used through several decades of speculation. Two sources of data need exploitation: a thorough search into pre-Silurian sediments for more adequate material of the earliest vertebrates, and research into the genetics of fundamental vertebrate features, such as bone formation, coupled with experimental embryological study of these same features.

EOCENE CONTINENTAL DEPOSITS IN THREE FORKS BASIN, MONTANA

G. D. Robinson, Edward Lewis, and Dwight W. Taylor
U. S. Geological Survey, Federal Center, Denver, Colo.

Thick continental deposits in the Three Forks basin have long been regarded as of early Oligocene to early Pliocene age. Recently collected mammalian and gastropod faunas demonstrate that more than 500 feet of the lowest exposed strata are of Eocene age. The discovery is of interest because only one other basin in southwestern Montana—near Lima, 100 miles southwest—has been known to contain Eocene deposits, and because it bears on regional tectonic history.

The Eocene strata, gently folded, unconformably overlie complexly deformed rocks as young as Late Cretaceous or possibly Paleocene. They grade upward into lithologically similar fossiliferous Oligocene strata.

Vertebrates from the top of the Eocene interval, near Shoddy Springs in upper Mud Spring Gulch (formerly Thompson Creek), include the condylarth *Hyopsodus* cf. *H. uintensis*, a tapiroid cf. *Isectolophus* sp., and an oreodont, ?*Protoreodon* sp. This fauna indicates late Eocene age, approximately that of the Uinta fauna.

Lower strata have yielded many species of fresh-water and land snails. Most are of wide or uncertain age range, but the fauna includes *Australorbis pseudoammonius* (Schlotheim), well-known from the Eocene of Europe and Asia, and in the United States most common in middle Eocene, though known from upper Eocene.

Recognition of another Eocene basin adds to the accumulating evidence that Eocene base leveling, often postulated, never occurred in western Montana, and that there was no substantial time gap between Laramide faulting and development of the intermontane basins. As they contain detritus from the Boulder batholith, the deposits help affirm its probable pre-Eocene age.

BIOGEOCHEMISTRY OF THE RARE EARTHS WITH PARTICULAR REFERENCE TO HICKORY TREES

W. O. Robinson, Harry Bastron, and K. J. Murata
Department of Interior, U. S. Geological Survey, Washington, D. C.

Hickory trees concentrate the elements of the rare-earth group in their leaves to a phenomenal degree, as much as 2300 ppm of total rare earths, based on the dry weight of the leaves. The average proportions of the individual elements (atomic per cent of the total rare-earth elements) in the leaves are Y 36, La 16, Ce 14, Pr 2, Nd 20, Sm 1, Eu 0.7, Gd 3, Tb 0.6, Dy 3, Ho 0.7, Er 2, Tm 0.2,

Yb 1, and Lu 0.2. The proportions of the rare-earth elements in the leaves and in the exchange complex of the soil on which the hickory trees grow are very similar, which indicates that the trees do not fractionate the rare earths appreciably.

The variation in the rare earths in the leaves and soils can be explained generally in terms of the relative abundance of the cerium earths and the yttrium earths, except for the element cerium. The large fluctuations in the proportion of cerium (Ce/La + Nd values of 0.16 to 0.86) correlate with oxidation-reduction conditions in the soil; this strongly suggests that quadrivalent cerium is present in oxygenated soils and is less available to plants than the other rare-earth elements which do not undergo such a change in valence.

GEOLOGY OF THE HANABANILLA HYDROELECTRIC PROJECT

Russell Roddy, Jr.
Apartado 8, Cienfuegos, Cuba

The Hanabanilla Hydroelectric Project, located in the southern part of Las Villas Province, Cuba, is under construction by Primera Central Hydroelectrica Cubana, an agency of the government of Cuba. Project design and construction supervision are under the direction of Tippetts-Abbett-McCarthy-Stratton, Engineers, New York.

The project includes earth and rock-fill dams across the Hanabanilla and Jibacoa rivers, a 4-km canal connecting the two reservoirs, an underground powerhouse with vertical penstock shaft and inclined service tunnel, and a 6700 tailrace tunnel

The project is located in the Trinidad-San Juan Mountains, a range that borders the south coast between Cienfuegos and Trinidad. Near the western end of the range, the Hanabanilla and Jibacoa rivers discharge from headwater canyons to meander across the floor of an ancient, sediment-filled lake. The Jibacoa River flows eastward; the Hanabanilla River, passing from the lake basin, flows westward through a 7 km reach of falls to lower its bed 250 m. The lake basin provides storage; the reach of falls on the Hanabanilla River provides the head for power generation.

The bedrock of the area consists of granodiorite, schist, limestone, and diorite gneiss. Regional strikes are east, roughly parallel to the trend of the range. The Hanabanilla Dam, powerhouse, penstock shaft, and the service and tailrace tunnels are in diorite gneiss, the oldest and most resistant rock of the area. The Jibacoa Dam is founded on lacustrine sediments which reach a depth of 75 m. The abutments are formed of limestone.

PHASE RELATIONS IN THE SYSTEM $CoAs_2$-$NiAs_2$-$FeAs_2$-As AT 800°C.

Eugene H. Roseboom, Jr.
Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C.

The system $CoAs_2$-$NiAs_2$-$FeAs_2$-As was investigated by heating dry mixtures of the elements involved or end-member phases in sealed evacuated silica tubes. The resulting phases were identified by X-ray powder diffraction methods and ore microscope.

The maximum arsenic content of phases stable with excess arsenic was determined by heating a weighed amount of metal in the presence of excess arsenic and measuring the increase in weight caused by arsenic combining with the metal. The minimum arsenic contents of these phases were determined by making runs of successively lower arsenic content until the first trace of a different phase lower in arsenic appeared. Some experimentally determined variations in the metal-to-arsenic ratios are:

Phase	Maximum As	Minimum As
Cobalt skutterudite	$CoAs_{2.96}$	$CoAs_{2.945\pm0.005}$
Loellingite	$FeAs_{2.00}$	$FeAs_{1.975\pm0.005}$
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Rammelsbergite	$NiAs_{2.00}$	$NiAs_{1.995\pm0.005}$

Homogeneous skutterudites synthesized with excess arsenic ranged from Co_{100} to $Co_{25}Ni_{65}$ and to $Co_{76}Fe_{24}$, and from $Ni_{76}Fe_{24}$ to $Ni_{49.5}Fe_{50.5}$ with extensive solid solution between these three series.

Loellingites with Fe/Co + Ni + Fe > about 0.70 and rammelsbergites with Ni/Co + Ni + Fe > about 0.95 are stable with excess arsenic.

There is a complete solid solution series between orthorhombic rammelsbergite ($NiAs_2$) and monoclinic $CoAs_2$. The change in symmetry is indicated by a gradual splitting of X-ray reflections beginning at about $Co_{75}Ni_{25}$. The loellingite $FeAs_2$-safflorite $(Co,Fe)As_2$-$CoAs_2$ series is nearly continuous with a narrow two-phase field near $Co_{80}Fe_{20}$ where the symmetry change occurs. In the loellingite-rammelsbergite series, there is a two-phase field between $Ni_{94}Fe_6$ and $Ni_{70}Fe_{30}$.

EVALUATION OF A PLEISTOCENE DATING METHOD USING URANIUM AND DAUGHTER PRODUCT RELATIONSHIPS*

John N. Rosholt
U. S. Geological Survey, Denver, Colo.

Many samples of uranium ore, fossil bones from stratigraphically controlled archeological sites, and coral limestone have been studied radiochemically. The abundances of Pa^{231}, Th^{230}, and Ra^{226} have been determined by radiochemical analyses utilizing alpha counting and compared to the uranium content to estimate the date of uranium deposition. The calculated times required for the growth of each isotope from uranium must be concordant in order to obtain the date of uranium deposition.

Three assumptions must be valid if the result of the sample analysis is to represent the true age: (1) the uranium free of daughter products must have been introduced into nonuraniferous material during a short interval, compared to the time for growth of the daughter products; (2) no measureable amount of external contamination by daughter products occurred since deposition; (3) measureable uranium or daughter products were not subsequently leached from the sample. Analyses of pre-Pleistocene bone samples indicate that a significant amount of uranium can be leached. The deviations of the result from the true age caused by leaching of uranium will operate in the direction which compensates for part of the deviation from the first assumption of short time accumulation of uranium, when concordant ages are obtained.

The comparisons of the results to the available C^{14} dates indicate that the estimated ages from fossil bones are not sufficiently accurate for archeological dating. However, the estimations obtained for many selected samples of uranium ore should be useful for geological purposes.

SYSTEM CaO-Al_2O_3-SiO_2-H_2O VI: THE GROSSULARITE—$3CaO \cdot Al_2O_3 6H_2O$ JOIN

Della M. Roy and Rustum Roy
Department of Geophysics and Geochemistry, College of Mineral Industries, The Pennsylvania State University, University Park, Pa.

A study has been made of the join C_3As_3-C_3AH_6 in the temperature range from 300°C. to 1000°C. and pressures up to 4000 atmospheres. Earlier work is found to be in error because of the shortness of runs and partly because of the failure to quench in the absence of water. Anhydrous grossularite having $\eta = 1.736$, $a_0 = 11.86$ can be prepared at least as low as 500°C. and is probably stable with water to at least 400°C. The equilibrium dissociation of the hydrogarnet solid solution is extremely complex, the maximum stability temperature of these phases is some 300–400°C. below values suggested by Yoder's work. It appears likely that stable solid solution may extend only from the C_3AH_6 composition to not more than the $C_3AH_2S_{1.5}$ composition. Evidence is presented for at least one new garnet solid solution between $C_{12}A_7$ and C_3AS_3, and the possibility of the existence of another

* Approved by the Director, U. S. Geological Survey.

type of garnet solid solution, corresponding to the phases prepared in short runs at the grossularite composition, is a moot point. Grossularite decomposes above 850°C. at 15,000 psi to yield wollastonite + anorthite + gehlenite.

SILICA STRUCTURE STUDIES VIII: HIGH SILICA PORTION OF THE SYSTEMS SiO_2-$NaAlSiO_4$ AND SiO_2-$LiAlSiO_4$ AND THEIR BEARING ON THE TRIDYMITE PROBLEM

Rustum Roy, T. Isaacs, and E. C. Shafer

Department of Geophysics and Geochemistry, College of Mineral Industries, The Pennsylvania State University, University Park, Pa.

Experimental "dry" and hydrothermal studies have been made of the systems SiO_2-$NaAlSiO_4$ and SiO_2-$LiAlSiO_4$ from 500–1200°C. at pressures below 1000 atmospheres. Tridymite can be prepared in the system SiO_2-H_2O at pressures as low as 1500 psi at about 900°C. As Na + Al is substituted the temperature of formation of tridymite decreases more or less regularly, so that with about 10 mol per cent $NaAlSiO_4$, tridymites have been made as low as 550°C. No unequivocal proofs for the attainment of equilibrium could be obtained in this temperature range for this system, but no abnormally strong variation in the inversion temperature was caused by this substitution. The low temperatures at which tridymite was obtained render invalid the use of the presence of tridymite in a rock as an indicator of temperatures above 870°C.

In the $LiAlSiO_4$ system the quartz is stabilized to higher temperatures with respect to tridymite, and a form (called silica-x) corresponding to high quartz preserved at room temperature is obtained metastably with a wide range of compositions. Equilibrium, however, shows the development of low quartz with no measurable solid solution. The problem of the formation of α-spodumene was complicated by the formation of α-eucryptite + petalite from the spodumene composition at low temperatures and pressures of up to 4000 atmospheres.

OVERTHRUST BELT OF WESTERN WYOMING AND ADJACENT STATES IN LIGHT OF FLUID-PRESSURE HYPOTHESIS

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The fluid-pressure hypothesis affords a possible explanation of the belt of overthrust faults (Darby, Absaroka, Bannock, and others) in western Wyoming and adjacent areas. This belt is composed of plates of Paleozoic and Mesozoic sedimentary rocks that seem to have been detached from their foundation along essentially bedding-plane faults, moved eastward a few score miles, and stacked imbricately one upon another. Here, as in other overthrust regions, long-continued geosynclinal sinking preceded intense deformation. The axis of maximum sinking apparently migrated eastward across the area during Early Cretaceous, Late Cretaceous, and Paleocene time. The youngest sediments overridden by each thrust plate accumulated much more rapidly than did older rocks below.

Rapid loading on top of an already thick pile of sediments would favor entrapment of pore water in the least permeable layers below. High fluid pressures thus generated would, under even moderate lateral stresses, facilitate shearing off of extensive plates several miles thick. Upbowing at the forward margin of such plates would cause erosion and decrease resistance, thereby permitting slow eastward movement of the entire mass.

Two alternative subhypotheses require consideration. The first assumes regional compression somehow concentrated in the uppermost part of the crust, with the overthrust block propelled by a push from the rear. The second assumes gentle flexing of the geosyncline and its marginal upland, with the overthrust block propelled by gravitational sliding down the intervening slope.

Neither of these accords conspicuously with current interpretations, and new field data for critical testing are required.

ORIGIN OF THE UPPER CRETACEOUS SHALE INCLUSIONS IN VOLCANIC AGGLOMERATE CUTTING PRECAMBRIAN AND PALEOZOIC ROCKS IN THE BLACK HILLS, SOUTH DAKOTA

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Approximately 9 miles south of Deadwood in the Black Hills of South Dakota a volcanic agglomerate crops out within a roughly elliptical area about four-tenths of a square mile in extent. The Cambrian-Precambrian contact dips toward the agglomerate on the west and south. On the north the Cambrian and overlying sediments are faulted down on the side of the pipe. The relative elevations of Precambrian and later sediments necessitates a fault with downthrow on the side of the pipe or an inward dip toward the pipe on the east. Within the coarsest agglomerate are fragments of fossiliferous shale. The fossils have been studied under the supervision of Dr. John Reeside, Jr., of the U. S. Geological Survey and belong to the Carlile of the upper Cretaceous.

At some time after the deposition of the Carlile a volcanic pipe penetrated upward to the surface. In the pipe at the surface pyroclastic material accumulated, supported by liquid lava in depth. The liquid lava column subsided and permitted the sinking of volcanic and sedimentary materials for a vertical distance of approximately 3500 feet. Whether the fossiliferous shales came from the then existing surface or were broken from the walls of the pipe is an unanswered question. The occurrence of upper Cretaceous shales surrounded by Precambrian sediments on the approximate axis of the Black Hills uplift may thus be explained without resort to uplift and erosion to the Precambrian by Carlile time.

PRELIMINARY REPORT ON THE SYSTEM ALBITE-NEPHELINE-WATER

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Preliminary phase equilibrium studies in the subsolidus region of the system albite-nepheline-water indicate: (1) A wide range of analcite solid solution throughout the system, probably extending from nepheline ($Na_2O \cdot Al_2O_3 \cdot 2SiO_2$) to albite ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$) composition. (2) Presence of a hydrated ($Na_2O \cdot Al_2O_3 \cdot 2SiO_2 \cdot H_2O$) form of nepheline at moderate pressures and temperatures. (3) Presence of a new metastable mineral in all compositions from nepheline to albite at very low temperatures and pressures.

Analcite has been produced from glasses of albite, analcite (anhydrous), natrolite (anhydrous), and nepheline compositions, and X-ray studies indicate that the cell dimensions vary directly with anhydrous composition between albite and nepheline. The P-T curve for the reaction analcite s.s. $\rightleftarrows$ nepheline hydrate I + H_2O, for nepheline composition, falls at approximately 225°C. at 10,000 psi. A point on the probable dissociation curve analcite s.s. $\rightleftarrows$ albite + $2H_2O$ is $\sim$ 355°C. at 15,000 psi. This curve will be a useful geological thermometer, if it can be demonstrated that the reaction is reversible, in that it will place a lower temperature limit on the formation of authigenic albite in sediments.

These studies are also expected to provide quantitative data on the pressures and temperatures of the zeolite facies.

FLYSCH AND MOLASSE

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Flysch and molasse have been variously considered to be, respectively: preorogenic (or synorogenic) and postorogenic sediments; graywacke and subgraywacke suites; and stratigraphic units

that are coarser and finer upward and outward from source. Eardley and White (1947) recommended that the terms not be circulated further.

Recognition of two major groups of sandstones (graded-bedded and cross-bedded) by Bailey (1936) and the effects of turbidity currents leads to the conclusion that flysch is an alternation of pelagic sediments and turbidites deposited in deep marine environments, and that molasse is a shallow marine and/or nonmarine sediment uninfluenced by turbidity currents. Neither mineralogy, position in tectonic cycle, stratigraphic relationships, nor sand-shale ratios provide a reliable basis for characterizing flysch and molasse; only sedimentary structures and fossils can be used. All properties and variations of these two contrasting facies can be rationalized on the basis of bathymetry.

Therefore, the writers conclude that: (1) the principle of dual sandstone nomenclature based on sedimentary structures proposed by Packham (1954) is valid; (2) molasse corresponds to certain *undathems* of Rich (1951), whereas flysch includes some of Rich's marine *clinothems* and *fondothems*, most of which cannot be separated; (3) the adjectives eugeosynclinal and miogeosynclinal (which properly refer to troughs in which volcanic rocks are respectively present and absent) should not be applied to clastic sediments; instead, flysch can be used for most sediments hitherto called eugeosynclinal, and molasse can be used for those called miogeosynclinal. The flysch-molasse distinction is more consistent, because volcanic rocks may occur with either type or be absent.

DEEP-SEA ORIGIN OF RADIOLARIAN CHERTS

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Consideration of the literature describing radiolarian cherts and results of deep-sea-sediment investigations made since Davis' (1918) summary of the origin of the Franciscan cherts (California) in which the "deep-water" hypothesis was rejected convinces the writers that the "deep-water" hypothesis of radiolarian cherts is correct. Not all problems raised by these cherts are resolved by this interpretation, but all commonly cited objections to it—association with coarse clastic strata, presence of ripple marks in associated beds, alternation of chert and shale beds, and presence of plant remains—can now be shown to be ambiguous for environmental determination owing to turbidity-current transport of "shallow-water" material into oceanic depths.

If the "deep-water" interpretation is correct, great vertical movements of the crust have taken place where radiolarian cherts are now exposed. Indentification of these cherts as ancient deep-sea sediments seems to answer the query as to the whereabouts in the geologic record of the counterparts of modern deep-sea trenches: they are in those geosynclines in which radiolarian cherts were deposited.

PHASE-EQUILIBRIUM RELATIONS IN A PORTION OF THE SYSTEM Na_2O-MgO-Al_2O_3-SiO_2 AND THE COMPOSITION OF RESIDUAL LIQUIDS FROM CRYSTALLIZATION

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Phase data for the joins ablite-cordierite-silica, albite-forsterite-cordierite, and albite-magnesium metasilicate-cordierite are presented, and the relation of these joins to seven quaternary invariant points is described. The portion of the regular tetrahedron, employed to describe relations in this quaternary system, between albite-forsterite-spinel-corundum and silica constitutes a large portion of the system and that portion of most interest to the petrologist. All the crystalline phases which are found in this portion are common rock-forming minerals or accessory minerals of either igneous or metamorphic rocks.

All compositions in the volumes albite-corundum-spinel-silica and albite-cordierite-spinel-silica proceed during crystallization toward the same goal, a soda granite in these potassium-free compositions.

RELATION OF ARCTIC STORMS TO SHORE-LINE CHANGES AT POINT BARROW, ALASKA

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Sponsored by the Office of Naval Research, Geography Branch, shore-line studies have been conducted since 1954 at Point Barrow, Alaska. Beach material is chert gravel with median diameter up to 15 mm. Offshore there is rapid decrease in size, with medians of 0.2 mm 400 feet from shore, and increase in proportion of quartz. In the summer of 1954 bottom profiles showed a steep drop with depths of 10 feet, 100 feet from shore, followed by a slope to 20 feet at a distance of 500 feet at one site and 1500 feet at two others. At the latter sites the surveys of 1955 found a bar 400 feet offshore rising to within 7 feet of the surface with intervening depths to 14 feet. Abnormally large waves in October 1954 are believed to have built the bar. This storm, worst in 40 years, developed the unusually large waves because of the extreme withdrawal of the pack ice. The storm tide rose 10 times the 1-foot height of the normal diurnal tide. The unchanged profile was thus in equilibrium with this storm. Other storms in 1954 and 1956 (pack ice prevented wave action in 1955) have been evaluated with respect to the exceptional storm. Comparisons indicate that, given a profile for this region, it should be possible to predict whether a storm exceeding a critical intensity will have no effect (stable profile) or will throw up a bar (unstable profile).

PETROGRAPHIC ANALYSES OF THE VARIOUS DENSITY SEPARATIONS OF COAL

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To determine the entity composition of the washed coal from each of the various zones of Deister concentrating tables, a petrographic study was conducted. The coal was from the Pittsburgh seam and was washed at the Robena Washery, United States Steel Corporation, Greensboro, Pennsylvania. Washed coal samples from 10 density zones were obtained from the middling, natural, and slime tables.

The fragmented samples were analyzed in reflected light by the point-count system of quantitative petrographic analysis. The most significant entity separation occurs in density zones 1 through 6 on the tables. Zones 7 through 10 are predominantly refuse (mineral matter) and show no selective trend in coal-entity concentration.

In general the results showed, from low to high densities: (1) vitrinite decreased, (2) micrinite increased, (3) fusinite increased, and (4) semifusinite, exinite, and resinite had no trend. Thus, density separation not only eliminates refuse coal but concentrates coal entities.

CHELATION AS A BIOCHEMICAL WEATHERING FACTOR

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Among conditions responsible for the solubilization and transport of rocks, minerals, and other ordinarily insoluble inorganic material, chelation reactions deserve more attention than they have heretofore received. Many organic compounds of higher plant and animal origin, especially those produced by microbial activity, are capable of forming soluble co-ordinate covalent compounds with various metallic cations and can dissolve insoluble inorganic salts. Lichens provide unusually fertile material for investigations in pedogenesis and biochemical weathering via chelation, because many of their constituents—*i.e.*, the lichen acids—are polyhydroxy polycarboxylates which complex metals. Experiments were conducted with 13 different lichens and with dolomitic limestone, gypsum,

rock phosphate, glauconite, granite, basalt, volcanic ash, red shale, and the A-horizon of exhausted tobacco soil. When the reaction mixtures were examined after incubation under different conditions, pH and conductivity changes showed that chelation or complexing reactions had taken place. This mechanism has also been shown to be operative in the solubilization of rock phosphate fertilizer, in the dissolution of enamel apatite in tooth decay, and with respect to the breakdown of rock and mineral particles in the soil under the influence of humus and other naturally occurring organic complexing agents.

PETROLOGY OF THE JACKPILE SANDSTONE, NEW MEXICO

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The Jackpile Sandstone, which is a name applied locally to a sandstone unit of economic interest, is the uppermost and thickest of a succession of quartzose sandstone units that intertongue with the Brushy Basin Shale Member of the Morrison Formation. The Dakota Sandstone unconformably overlies the unit. The Jackpile Sandstone is the principal uranium ore-bearing unit in the Laguna district and is well exposed north of Laguna, New Mexico, 45 miles west of Albuquerque. Surface exposure and isopachous maps show that the sandstone occupies at least one and possibly several troughs. The main trough in the Laguna region is approximately 9 miles wide, probably considerably more than 30 miles long, as much as 190 feet deep, and trends northeastward.

The Jackpile Sandstone ranges from graywacke and arkose to orthoquartzite. Most of the unit is cemented by clay, but calcite cement is present in the lower part. Most of the orthoquartzite occurs in a thin zone at the top of the unit and is the result of chemical weathering of detrital feldspars and removal of the resulting clays on the pre-Dakota erosion surface. The detrital fraction of the sandstone tends to be less mature and coarser in the lower half.

Areal configuration and certain textural properties suggest that the Jackpile Sandstone originated as a fluvial flood-plain deposit. It was folded before the deposition of the Dakota Sandstone.

QUANTITATIVE X-RAY MODAL ANALYSIS OF SEDIMENTS FROM THE PERU-CHILE TRENCH

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Detailed petrographic examination of the suite of cores recovered by ATLANTIS off the coast of Peru and Chile during 1955–1956 has been undertaken. To implement this study, an x-ray technique was developed, capable of providing rapid modal analyses of fine-grained mineral mixtures with an uncertainty of less than ±5 per cent. The analysis requires about 30 minutes and includes quantitative determination of halite, quartz, the carbonates, microcline, the plagioclases, iron oxides, 10, 7, and 14 Å micaceous minerals, and, by difference, amorphous materials including volcanic glass.

Preliminary results from coring profiles off Antofagasta and Arica, Chile, show systematic differences in mineralogy which may be related to the provenance areas, and the meteorology and hydrology of the depositional site.

The northern profile grades from sandy silt at the coast to dense muds in the Peru Trench and consists dominantly of quartz and labradorite, with lesser amounts of chlorite, amphibole, pyroxene, micas, and kaolinite. Volcanic glass of basaltic composition is abundant and increases in quantity at depth. At Antofagasta, the same size gradation is observed, but quartz, albite, and muscovite are the dominant minerals with accessory amphibole, illite, and kaolinite. Here glass is much less common, but of similar composition to that at Arica. These mineralogical differences are shown to be directly controlled by the lithologies of the prevenance areas. The composition of the volcanic glass is determined by the most recent volcanic activity in the area, distributed by prevailing winds and currents.

PRELIMINARY INTERPRETATION OF PERMO-CARBONIFEROUS STRATIGRAPHY IN EAST-CENTRAL IDAHO

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Complex facies changes occur in the Permo-Carboniferous strata between the eugeosyncline of central Idaho and the miogeosyncline near the Montana border. In southwestern Montana the sequence includes up to 2000 feet of Lower Mississippian Madison Limestone, 1000 feet of Big Snowy and Amsden limestone and fine clastics, and up to 3000 feet of Quadrant Quartzite. In central Idaho (western Bayhorse quadrangle) the Carboniferous is represented by Milligen Shale (mostly Mississippian) and Wood River Sandstone (partly Pennsylvanian), approximately 3000 and 8000 feet thick, respectively. In the intervening Lemhi and Beaverhead ranges Milligen equivalents are thin to absent, and an arch is postulated between the Milligen and upper Madison (Mission Canyon) basins. This may also account for the absence of fine clastics in the Mission Canyon in contrast to the shaly Lodgepole (lower Madison) Limestone, which probably interfingers with the lower Milligen.

Between the Montana border and the Bayhorse region the Milligen is overlain by thousands of feet of "Brazer" Limestone. Shaly units are attributed to interfingering with Milligen to the west and Big Snowy to the east. However, much of the "Brazer" appears to be Pennsylvanian and even Permian (Wolfcampian), intertongued and overlapped by Wood River-type sandstone and grading eastward into Quadrant Sandstone and, possibly, lower Park City Limestone.

There preliminary data suggest the "Brazer" of east-central Idaho is a great Late Mississippian to Early Permian carbonate wedge between areas of dominantly clastic deposits. This unit, which may extend into southern Idaho, deserves a new formation name.

ALTERATION OF BIOTITE UNDER MESOTHERMAL CONDITIONS

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The complex chemical composition of biotite is doubtless the cause of a variety of alteration products when it has been altered by hydrothermal solutions at moderate temperatures and pressures. As a rule biotite is unstable under hydrothermal conditions and alters to numerous minerals which seem to depend primarily on the composition of the solution at any given point. Common alteration products are green biotite, chlorite, muscovite, sericite, hydromica, kaolinite and other clay minerals, calcite, epidote-zoisite, leucoxene, rutile, pyrite and other sulfides, and less commonly several other minerals.

A complex of several minerals which have replaced biotite within a single thin section is a common occurrence and is proof that equilibrium is not normally attained during hydrothermal alteration. The structure of biotite exerts a strong control on the alteration as shown by the occurrence of two or three minerals in bands parallel to the cleavage of the biotite.

The original composition of biotite has a strong influence on the alteration products, but minerals such as calcite retain only oxygen of the original elements.

GROWTH STAGES AND SPECIFIC VARIATION IN DEVONIAN-MISSISSIPPIAN CONODONTS

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Many long continuous conodont-bearing sections of Devonian-Mississippian rocks were the object of recent study in the Mississippi Valley, and thousands of excellently preserved specimens were collected from selected zones. From these extensive collections it was possible to establish complete

series of growth stages for many species, as well as suites of mature specimens exhibiting rather wide ranges of variation. Recognition of these growth stages greatly clarify generic and specific relations of many key species and in some cases establish with little doubt obscure lines of phylogenetic evolution.

Other important benefits also resulted. Distacodids (*i.e.*, simple cones), long considered indigenous to Ordovician-Silurian rocks—and almost universally interpreted as admixtures when found in the upper Devonian—have been recognized in all growth stages, thereby proving them to be indigenous Devonian faunas.

Furthermore, the studies clearly indicate that greater emphasis must be placed on ontogenetic study of key species if the full value of conodonts as stratigraphic indices is to be realized. The studies also show that a new species description should include illustrations of immature growth stages if it is to be adequate for definition of that species.

GRANITIC ROCKS OF NORTH HALF OF MT. ABBOT QUADRANGLE, SIERRA NEVADA, CALIFORNIA

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The north half of the 15-minute Mt. Abbot quadrangle lies across the high crest of the Sierra Nevada. The granitic rocks (Cretaceous) that underlie most of the area form eight large discordant plutons, varying from quartz diorite to alaskite; the largest pluton within the area is of coarsely porphyritic quartz monzonite. Pre-batholithic metasedimentary and metavolcanic rocks, and metagabbro and metadiorite, are of minor extent. The porphyritic quartz monzonite sent gently dipping dikes as much as 200 feet thick into its walls, and these dikes are so abundant in places as to make up more than half the area of exposed contacts. A broad border zone of protoclastic flaser gneiss was formed in part of the pluton and in the adjacent wall rocks and dikes.

A zone between granodiorite and calcareous metasedimentary rocks swarms with dark inclusions which here clearly originated by progressive hybridization of calc-silicate xenoliths, the changes taking place within a few tens of yards of the contact. The zenoliths were amphibolitized concentrically and reconstituted to typical dark-inclusion texture and mineralogy and were drawn out from blocky xenoliths into spindle shapes. Elsewhere, large irregular xenoliths of metadiorite were assimilated by alaskite, and within the resulting complex is a thick series of alaskite flow layers crowded with xenocrysts of hornblende and biotite showing graded "bedding".

Although all the varied granitic plutons were intrusive, assimilation of mafic wall rocks by felsic magmas may have contributed greatly to their diversity.

CHEMICAL FACTORS IN CARBONATE-QUARTZ CEMENTATION

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The replacement of quartz, both authigenic and detrital, by secondary carbonate minerals is common in many sedimentary rocks. For such replacement to proceed simultaneously the quartz must be dissolved and carbonate precipitated from an aqueous solution present as a thin film between the two solid mineral phases. Optimum conditions for quartz solution and carbonate precipitation obtain in alkaline solutions. Knowing the equilibrium constants for carbonate equilibria in water, one can calculate the pH of pure water originally saturated with atmospheric CO_2, then sealed off from further exchange with the atmosphere, and put into equilibrium with solid $CaCO_3$, to be 9.88 at 25°C. At pH around 9.8, monomeric H_4SiO_4 in solution partially dissociates to give silicate ions, approximately doubling the solubility of quartz at lower pH values. Thus the very presence of solid carbonate may be responsible for raising the pH to the point where quartz has a greater solubility. The continuation of the process of replacement must involve diffusion gradients

of both carbonate and silica species from thin film to open pore fluid. The pressure and temperature coefficients of the equilibrium constants are such that, at 65°C. and 1000 atmospheres, the equilibrium pH should be approximately one unit lower; at a pH of 8.8 quartz is much less soluble, and optimum conditions for carbonate replacement are not attained. The geologic implications are discussed in terms of the possible *P-T* conditions of cementation and of the possibility of the observed cements having been precipitated early in diagenesis.

ALTERATION OF ACCESSORY ALLANITE IN GRANITES OF THE ELBERTON AREA, GEORGIA

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Unusual alteration aggregates have pseudomorphically replaced euhedral allanite on a pervasive basis throughout most of the Elberton granites of northeast Georgia. Allanite, originally about 0.3 per cent of the granites in an area of more than 300 square miles, is now present as sparse, zoned residuals, in varying states of metamictization, which previous workers have not reported. The alteration products include bastnasite, huttonite (?), hematite, and a pale-yellow isotropic, or nearly isotropic mineral. Textural and crystallographic evidence indicates that the principal alterations resulted not from simple metamictization but rather from reactive solutions, probably deuteric, possibly much younger, which attacked the allanite along crystal and zone boundaries. A similar phenomenon has been noted in other granites of northern Georgia. The stability of these assemblages in weathering profiles has been studied. Their conversion to nondescript red iron oxide-clay aggregates is important in understanding the weathering geochemistry of U, Th, and the rare-earth elements in these granites. It also explains why investigators of heavy minerals in saprolites of these rocks have failed to recognize allanite and its alteration products as the most common accessory mineral in these granites and emphasizes one of the limitations of saprolite heavy-mineral studies.

LEAD IN POTASSIUM FELDSPARS ASSOCIATED WITH ORE DEPOSITS

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The lead content of potassium feldspars from stocks associated with Cordilleran mining districts is being investigated. Spectrochemical analyses are made with an Applied Research Laboratory 1.5 meter, 24,000 line per inch, grating spectrograph. Internal standardization is accomplished by the addition of 1 per cent by weight of Bi_2O_3.

The quantitative data gathered on the Robinson (Ely) district, Nevada, and the West Mountain (Bingham) district, Utah, indicates that the trace lead content in the potassium feldspar of each district falls into a distinct statistical population group. A decided grouping around 26 ppm occurs for the Robinson (Ely) district and around 70 ppm in the West Mountain (Bingham) district.

Each of the populations is closely grouped about a mean. If this holds true on further investigation, only a few samples may be necessary to be accurately representative of a given stock.

VARIATION OF ALKALI FELDSPARS IN IGNEOUS ROCKS

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On the basis of a purely mineralogical study of alkali feldspars, the results of which have been described earlier (1954), a detailed petrological study of the feldspars from carefully selected igneous rocks has been made.

Various rhyolites and trachytes have yielded homogeneous and perthitic sanidines and anorthoclases. The Slieve Gullion composite ring dike of porphyritic felsite and granophyre and the Beinn an Dubhaich granite gave perthites containing a monoclinic K phase, together with anorthoclase and sodic plagioclase. The Arran and Mourne granites gave orthoclase-low plagioclase perthites. The Dartmoor granite and the Southern California batholith gave orthoclase-microcline-low-plagioclase perthites.

The present assemblages are interpreted as the results of a series of reactions, sanidine → two sanidines (or sanidine plus anorthoclase) → orthoclase plus low sodic plagioclase → microcline plus low sodic plagioclase, that have taken place in an originally homogeneous feldspar. Although the volatile content and the pressure undoubtedly have important effects it is natural to focus attention on the cooling rate in view of the good correlation between the nature of the feldspar and the inferred cooling rates of the above rocks.

Going down the series it is deduced that the reactions require both lower temperatures and slower cooling rates. During cooling, the feldspar proceeds along the series of reactions until the cooling rate becomes too high for the maintenance of equilibrium. A set of phase diagrams using these ideas has been prepared.

SELECTION OF QUARRY SITES IN THE DIMENSION LIMESTONE BELT OF INDIANA*

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Geologic methods have not been used extensively by operators in prospecting for new dimension-stone quarries in the Salem (Meramec) limestone of Indiana.

Recent detailed field studies of dimension-stone quarries and laboratory studies of thin and polished sections indicate that limited correlations may be made with four Salem dimension-stone lithologies; these calcarenite lithologies can be identified by the relative abundance of certain types of fossil fragments and fossils which form this microcoquina. Determination of the environments in which these fossils and fragments were deposited and by which these lithologies were modified aids in locating favorable dimension-stone sites and in estimating the thickness of usable stone at these sites. Some minor variations in lithology, which adversely affect the economic value of the stone, are not predictable. Physiographic study aids in selecting quarry sites likely to have the preferred buff-colored limestone and in eliminating prospective sites containing such deleterious results of differential solution as sink holes, mud seams, and excessive loss of cement.

MINERALIZED SUBMARINE SLIDES IN THE SOUTHEAST MISSOURI LEAD DISTRICT

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Brecciated carbonate and shale zones formed by submarine slides are important ore-controlling structures in the Southeast Missouri lead district. Excellent three-dimensional exposure in mine workings and thousands of diamond-drill holes permit detailed study of the slides.

The breccia zones occur along the margins of depositional basins in the lower part of the Upper Cambrian Bonneterre Formation. Differences in degree of compaction between calcarenites in submarine ridges and fine-grained basin carbonates lead to oversteepening of dips in the gradational zone on the flanks of ridges and mass movement of partially consolidated sediments into the basins. As a slide moved down the flank of a ridge it gouged deeply into underlying sediments; at the foot of the ridge the base of the slide flattened to become parallel with bedding, and momentum of the

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mass was checked by the buttress of basin sediments. The toe of a slide is characterized by a piled-up ridge of breccia with underthrust relationships to adjacent basin sediments. Successive periods of sliding result in younger slides cutting older ones to form breccia masses of considerable thickness.

The breccia masses are host rocks for lead-zinc ore bodies where an underlying contact favorable for mineralization of the bedded type is cut by a slide. The disturbed and jumbled zone permitted easy movement of ore solutions resulting in ore bodies up to several thousand feet of strike length and 130 feet in height. Lead, zinc, and iron sulfides occur as disseminated replacements of breccia matrix.

GEOCHEMICAL STUDY OF THE DULUTH LOPOLITH

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The Duluth lopolith is composed largely of mafic rocks: gabbro, norite, troctolite, and anorthosite, with minor amounts of granophyre or "red rock", particularly in the upper part. Forty-five samples, excluding granophyre, were obtained at approximately half-mile intervals along two traverses across the strike of the lopolith. Each was crushed and separated into its constituent minerals, and the olivines, pyroxenes, and plagioclases were analyzed spectrographically. Along the Hame-Brule traverse, the concentration of both major and trace elements shows strong local fluctuations but no apparent over-all trend. Along the Kawishiwi traverse, the MgO, NiO, and Cr_2O_3 of the olivines show a progressive increase upward, whereas the FeO, MnO, CoO, CuO, and ZrO_2 decrease upward, and the TiO_2, V_2O_3, and Sc_2O_3 exhibit no consistent trend. Associated feldspars show an upward increase in MnO and CaO; an upward decrease in MgO, FeO, CuO, and Na_2O; and an erratic variation in NiO, TiO_2, and K_2O.

The association between major and trace elements in these minerals is generally predictable on the basis of geochemical theory. However, the trends in the Kawishiwi area are just the reverse of the trends found in most stratified mafic igneous bodies. They can be explained as the result of multiple injections from a differentiating magma source, with each successive injection emplaced immediately beneath its predecessor. In the Hame-Brule area successive injections were probably crosscutting, yielding erratic distribution of younger fractions along the traverse line.

UPPER JURASSIC-LOWER CRETACEOUS CYPRIDEINAE (OSTRACODA) IN THE BLACK HILLS

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Species of the subfamily Cyprideinae are characterized by an easily recognized ventro-anterior notch. With two exceptions, this subfamily is known only in sediments younger than uppermost Portlandian in Germany, and lower Purbeckian in England. *Cypridea spinigera* (Sowerby), 1836, (Lower Cretaceous to Eocene) is supposed to have been collected from the Oxford Clay (lower Upper Jurassic), and *C. postelongata* Bernard, Bizon and Oertli, 1957, with a very reduced notch, is described from the Bathonian (Middle Jurassic) of France. None of the more than 25 collections from the Morrison Formation in the Black Hills contains species of this group, but more than 50 samples from the Inyan Kara Group contain abundant representatives of notched species.

The ostracode faunules from the Black Hills described as "Morrison" by Roth in 1933, and by Harper and Sutton, 1935, contain species with ventro-anterior notches, as well as other species that are common in the Inyan Kara Group. This, plus the absence of *Theriosynoecum* Branson, 1935, a genus known only from the Morrison Formation, suggests that the ostracodes described by Roth and by Harper and Sutton may be of Inyan Kara age.

The abundance of notched forms in rocks of the Inyan Kara Group contrasted to their absence in the underlying Morrison Formation may be a useful criterion for separating the two.

FRACTURE PATTERNS IN THE BEARTOOTH MOUNTAINS, MONTANA AND WYOMING

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Studies of 25,000 joints and five groups of dikes in Precambrian gneisses in the Beartooth Uplift are compared with 3600 lineaments on aerial photographs. The lineaments represent faults, fracture zones, and dikes. Four major vertical trends—N. 15°–20° W., N. 40°–45° W., N. 40°–55° E., and N. 65°–70° W.—and three less well-defined trends—E.–W., N. 60° E., and N.–S. to N. 15° E.—are indicated by both sets of data. The major fractures are explained by folding with maximum shortening along a NW.–SE. line. Other fractures probably formed later.

No significant variation in pattern is found on the southwestern slope of the uplift. Several additional sets of inclined fractures appear in the pattern on the northeastern slope, where structural relief exceeds 15,000 feet, and where the margins are locally overthrust more than 1200 feet.

Five groups of dikes are found. The oldest are ortho-amphibolite, may be pre-granitization, and are at least 2.7 b.y. Other groups are Archean metabasaltic dikes, unmetamorphosed Precambrian quartz dolerites, probably Tertiary, olivine dolerite dikes, and Laramian porphyry dikes. All these dikes have the same trends, parallel to fractures and joints. Thus early Precambrian fractures controlled deformation in the Precambrian and Laramian. Photographs show minor horizontal displacements on crosscutting fractures and Precambrian dikes. Laramian movements in the core of the uplift were predominantly vertical.

"CLARKE" CONCEPT AND ITS USE IN GEOCHEMISTRY

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The history of quantitative measurements and estimates of the distribution of chemical elements in the earth's crust, with its lithosphere, troposphere, hydrosphere, and biosphere, is outlined briefly.

The first table showing the distribution of chemical elements in the upper part of the earth's crust expressed in per cent of weight was prepared by F. W. Clarke in 1889. It contained mostly major elements. His last table, presented with H. S. Washington in 1924, included 50 elements.

In 1922 A. E. Fersman, in recognition of Clarke's work, proposed that the figure expressing the abundance of an element be called "clarke." The average concentration of an element, expressed in per cent by weight or by atoms, represents a normal clarke (weight or atomic). The unit has long since been adopted by most Russian geochemists and is widely used by many others throughout the world.

The use of "clarke" as a geochemical unit in the study of the minor elements (Be, B, Ti, V, Cr, Co, Ni, Mo, Cu, Zn, Ga, Ge, Sn, Y, and La) in the ash of American coals permits a simplified comparison between the extent of their relative concentration or deficiency, with the normal clarkes of the the earth's crust. The average concentrations of some of the elements (Be, B, V, Cr, Co, Ni, Mo, Ga, Ge, Y, and La) particularly in the inherent ash of some woody-type coal, may be from a few to several tenfold and more clarkes. The maximum concentrations of Be, B, Mo, Ga, Ge, Y, and La in some coals reach several hundreds to even tens of thousands of clarkes.

STROMATOPOROID FAUNA FROM THE DEVONIAN OF THE CANADIAN ROCKY MOUNTAINS

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Stromatoporoids are abundant in the reefal facies of the Fairholme Group in the Front Ranges of Alberta and British Columbia but are rare in the overlying Alexo and Palliser formations. In

the Cairn Formation, at the base of the Fairholme Group, stromatoporoids are the most conspicuous rock-forming organism and grew in extensive biostromes. The preservation of these fossils is generally unsatisfactory for detailed morphological studies, for most specimens have been obscured by dolomitization and recrystallization, and many cannot be identified.

The genera *Anostylostroma, Actinodictyon, Actinostroma, Amphipora, Labechia, Parallelopora, Stromatoporella, Stachyodes,* and *Stictostroma* are represented in the fauna of these beds. Ten species are recognized, of which nine are new. A new genus is established to include stromatoporoids that have generally been referred to *Clathrodictyon,* in which the space between the well-defined laminae is occupied by an irregular tangle of calcareous fibers, and the typical cystose structure of *Clathrodictyon* is lacking. This interlaminar structure appears in *Clathrodictyon carnicum* Charlesworth, is better developed in *C. katavensis* Yavorsky and *C. tschusovensis* Yavorsky, and is even more marked in a new species from Alberta.

The stromatoporoid fauna bears little resemblance to the faunas of the Upper and Middle Devonian of Europe or Asia.

GEOLOGIC BASIS FOR ICE-AGE CLIMATOLOGY

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The Tertiary period was marked by cooling and increasing aridity on continental areas and by cooling of the oceans. The Pleistocene Ice Age does not seem to be entirely an outcome of this trend because it provides no mechanism for increasing precipitation in glaciated regions. Although many theories based on terrestrial as well as astronomical factors have been put forth there is still lack of agreement as to what initiated the glacial interval.

There is, nevertheless, an accurately dated geologic event which coincides with the beginning of the glaciation in the Northern Hemisphere—namely, the closing of all waterways between North America and South America. This diverted increasing amounts of warm water into northern regions, which were sufficiently cold and needed only increasing snowfall to support ice fields. This event, together with the closing of Tethys seaways from the Indian Ocean to the Atlantic Ocean had the effect of creating a meridional circulation in the Atlantic which carried tremendous heat energy into northern latitudes.

Following this line of reasoning the Greenland and Eurasian ice sheets formed first, and the expansion of the North American sheet followed through progressive southward deflections of the storm tracks. Eventually the western cordilleran ice cap formed with ice entering the Pacific. Cooling of the northern Pacific and North Atlantic eventually cut evaporation and precipitation causing recession of northern glaciers. The eventual rewarming of the ocean with increasing precipitation explains the return of glaciers. Subsequent oscillations reflect the lag between cooling and warming the oceans and corresponding effects on land.

GEOLOGIC RECORD OF A DEGRADATIONAL STREAM, MIDDLE BRAZOS RIVER TEXAS

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A valley survey of the Brazos River from near Waco to Knox City, 500 miles upstream, has been made for the purpose of determining the distribution of the stream's deposits and its channel characteristics. From this, a stream history of uninterrupted though varied degradation is indicated.

The river is entrenched across pre-Tertiary outcrop bands which through their resistance control the gradient, channel form, sedimentary load, and stream habit. Braiding and meandering are confined, respectively, to easily erodable bedrock at the upper and lower survey extremities. Incised meanders are developed in resistant rocks between.

Several alluvial Pleistocene terraces, ancestrally identical to the flood plain, are developed where the valley has been widened by the braiding and meandering processes. A degradational origin for the terraces is indicated by the following depositional features. Surfaces slope riverward and are unpaired. Underlying deposits are thin (25–40 feet) and composed gradationally of materials considered to be one channel migration sequence: basal gravels are interpreted as initial bedload, the successively finer constituents above as subsequent bar and flood-plain deposits.

Two terraces occur upstream, and three downstream; correlations cannot be made through the intervening narrow valley. One terrace, composed of previously named "Seymour beds", can be dated as Kansan-Yarmouthian because of interstratified Pearlette ash. A molluscan fauna corroborates this age. Only relative ages can be assigned otherwise; superior terrace height always indicates greater antiquity.

A theory of climatic variation explains most favorably the terrace origins. Accordingly, sloping alluvial surfaces were formed behind migrating channels during times of slow degradation; scarps were cut when heavy runoff accelerated the erosional paces.

RELATIONSHIP OF ORE TO PORPHYRY IN THE GREAT BASIN

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The close association of granite type rocks (alaskite through diorite) with hydrothermal deposits of Mo, W, Ag, Au, Pb, Zn, Hg, and Cu in the Great Basin province is well known. However, most of the Great Basin granitic masses are practically devoid of associated mineralization. In an effort to determine if there are significant differences in these "barren" and "productive" granites, a program of mapping eastern Great Basin granitic areas has been carried out during the last two field seasons, and reliable data have been accumulated on 15 hitherto little-known or poorly mapped granites.

Information from the present work and a brief examination of many described "productive" and "barren" granitic areas, coupled with a survey of Great Basin literature, shows that a great majority of productive regions have stocks and dikes of intrusive porphyry occurring in significant proportions associated with the granitic rock. In some productive districts granitoid rocks are absent, and only stocks of intrusive porphyry are present. With few exceptions where granitoid rocks are without significant intrusive porphyry, W may be present, but other useful metals are essentially absent.

In searching for large new hydrothermal ore districts within the Great Basin, areas containing granitoid rocks only could be bypassed and efforts confined where significant amounts of true intrusive porphyry exists either alone or with granitoid rocks. A plea is here made to field workers to differentiate between granitoid and intrusive porphyry rocks and to record such data clearly in reports.

SINGLE CRYSTALS OF ZINC SULFIDE WITH 6- AND 18-LAYER POLYTYPE STRUCTURE

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Three new structures of naturally occurring zinc sulfide have been reported by Frondel and Palache (1950), and crystals containing 2-, 3-, 4-, and 6-layer structures intermixed on a submicroscopic scale have been described by Strock and Brophy (1955). Two single crystals of 2 mm size have recently been found in a batch of crystals grown by vapor-phase methods, in which X-ray precession photographs reveal only one periodicity along [00.1], namely 6-layer and 18-layer. These are the only examples we have found of an unmixed polytype structure in synthetic products. The stacking

sequence of the 18-layer polytype is not yet determined, but the X-ray pattern is basically hexagonal and not rhombohedral. Both crystals have strong optical birefringence banded perpendicular to the *c* axis on a scale of 1–10 micron per band. The birefringence ranges from a maximum of 0.024 to 0.0095 with at least 10 intermediate finite values. These discontinuities in birefringence have been interpreted as boundaries between regions of alternating structural polarity. The value of birefringence within a band depends on the number of layers at which stacking reversals occur (maximum for 100 per cent layer reversals as in pure 2-H structure), in a completely analogous manner recently proposed to account for the reverse case of birefringent 3-layer crystals. In the latter case, stacking (or sequence) reversals generate birefringence in an intrinsically isotropic crystal.

DECCAN VOLCANIC ROCKS OF BOMBAY, TROMBAY, AND SALSETTE ISLANDS, INDIA

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Volcanic rocks of the Bombay area are correlated with the upper stage of the Deccan traps and are late Cretaceous to early Tertiary. The lavas of the Ghats are undeformed and remarkably uniform in composition, while ash beds are rare. In contrast, those of the Bombay area dip 10°–15° W., include monchiquites, trachytes, and rhyolites as well as basalts, while ash beds and other pyroclastics are common. Deuteric albitization of the mafic lavas is not uncommon.

The petrography of the rocks has been studied in detail, and 10 new chemical analyses are presented. Differentiation is attributed to crystal fractionation. Marginal phases of the tholeiitic Deccan province of India, like the lavas of the Bombay area, show distinct affinities with alkali basalts and their derivatives. This is similar to features shown by marginal phases of the tholeiitic Karroo province of southern Africa.

SANTAFEITE, A NEW HYDRATED VANADATE FROM NEW MEXICO*

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Santafeite is a new hydrated vanadate found in the Grants uranium district, McKinley County, New Mexico, in the spring of 1951. It has the formula $Na_2O \cdot 3MnO_2 \cdot 6(Mn,Ca,Sr)O \cdot 3(V,As)_2O_5 \cdot 8H_2O$. The mineral occurred as an encrustation on an outcrop joint surface of Todilto limestone in small rosettes of acicular crystals. Physical and optical properties are: perfect (010) and distinct (110) cleavages, black color, brown streak, subadamantine luster, very brittle, readily fusible in an alcohol flame to a dull black bead; translucent only in very small fragments, pleochroic from dark reddish brown to yellowish brown, with absorption $X > Y > Z$; $X = c$, $\alpha = 2.01$, distinct dispersion. X-ray studies by rotation, Laue, and powder-diffraction methods indicate orthorhombic symmetry, space group V^{11}_h, Pmca, with cell dimensions $a_o = 9.26 \pm 0.02$ Å, $b_o = 30.02 \pm 0.02$ Å, $c_o = 6.28 \pm 0.02$ Å.

The mineral is named santafeite, after the Atchison, Topeka, and Santa Fe Railroad Company, in recognition of its pioneer exploration and development of the uranium deposits in New Mexico.

OROGENIC MOVEMENTS DURING LAFAYETTE TIME

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Since mid-Cretaceous time repeated uplift and depression, both local and regional, have occurred in the Southeastern States. Erosion has reduced the rising highlands by at least a mile, while the

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partly exposed and partly submerged Coastal Plain has been subjected to sedimentation and depression.

The last important movement occurred when Coastal Plain and Piedmont were depressed to receive the Lafayette Formation and then promptly, but not completely, re-elevated. Coincidentally the mountains were probably raised slightly above their old positions. In the upper Piedmont erosion has left only thin remnants of the Lafayette on flat divides, and in a narrow belt along the coast it has been replaced by younger deposits during the swinging sea level of the ice ages.

Lafayette gravels, almost exclusively quartz, are present on valley slopes and divides. They were not deposited by present streams but are residual accumulations from older formations chiefly the Black Mingo (Eocene), small remnants of which remain near the inner margin of the Coastal Plain. In the Piedmont the basal gravels form the so-called "stone lines". Pebbles showing good cleavage are common, and similar quartz occurs in veins of the Piedmont and mountains. It is found from Virginia southward to Tylertown, in southwestern Mississippi.

Near the end of the Pliocene sea level was lower than now, and the melting of all polar ice would raise sea level perhaps 100 feet. Therefore the Lafayette cycle has lowered the Carolina coast more than 100 feet.

MAGNESIAN HORNFELSES IN THE AUREOLE OF THE BALD MOUNTAIN BATHOLITH, ELKHORN MOUNTAINS, NORTHEASTERN OREGON

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Magnesian hornfelses formed by contact metamorphism of serpentinized ultramafic rocks occur in the southwestern and northern parts of the aureole of the Bald Mountain batholith, in the Elkhorn Mountains of northeastern Oregon. Relict textures in serpentinites and ratio of olivine (Fa_{10-14} in southwest, Fa_{20-24} in north) to enstatite (Fs_{3-6} in southwest) in slightly serpentinized rocks indicate original dunites, saxonites, and harzburgites.

Within a mile of the contact, tremolite-actinolite occurs in nearly all ultramafic rocks. Approaching the batholith, tremolite becomes richer in Fe, and within 1000 feet of the contact amphibole is generally iron-poor actinolite.

Green spinel (n = 1.757–1.769) occurs in most magnesian hornfelses within 650 feet of the batholith. It appears as small irregular granules in actinolite and as grains bordering relict olivine; in hornfelses nearer the batholith, some pleonaste occurs as rods elongated parallel to the cleavage in actinolite. Grains are larger, and crystals more nearly euhedral, toward the batholith.

Regenerated olivine appears in many hornfelses within 350 feet of the batholith. It is poikiloblastic, rarely altered, contains no prominent secondary network of iron ore, commonly surrounds pleonaste, and is richer in Fe (Fa_{20-25} in southwest, Fa_{27-28} in north) than is relict olivine. Typical assemblage of hornfelses is actinolite, pleonaste, iron ore, and regenerated olivine.

Bronzite occurs within 100 feet of the batholith. It (Fs_{18-20} in southwest, Fs_{20-23} in north) has dimensions of several millimeters, is poikiloblastic, and associated with actinolite, regenerated olivine, and pleonaste.

ZIRCONS IN THE METAMORPHIC AUREOLE OF THE BALD MOUNTAIN BATHOLITH, ELKHORN MOUNTAINS, NORTHEASTERN OREGON

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Zircons were extracted from 37 metamorphosed sediments in the aureole of the Bald Mountain batholith of northeastern Oregon by crushing 200–400 grams of each rock and concentrating the zircons with bromoform and a Frantz separator. After mounting, lengths and widths of 300 crystals were recorded whenever possible. For 18 rocks in which less than 300 zircons were recovered, every

crystal was measured. Recovery of zircon from 11 rocks was inadequate (2–87 crystals) for statistical treatment.

At metamorphic intensities below pyroxene-hornfels facies, zircons show no changes. As the contact of the batholith is approached, zircons develop overgrowths in argillaceous rocks of pyroxene-hornfels facies which result in a gradual change from rounded grains into euhedral zircons.

In the Elkhorn Mountains, zircon studies offer one possible method for distinguishing granitic rocks of magmatic origin from similar rocks of metasomatic origin. In thoroughly granitized rocks, euhedral zircons are distinct from euhedral zircons in associated granitic rocks of magmatic origin. Zircons in granitized rocks are distinguished by simpler crystal habits, greater elongation ratios, and more variability among samples in crystal size, elongation ratio, and number of crystals present. Major differences between the two contrasting kinds of zircons can be shown by comparison of various types of curves constructed from statistical data.

PHYSICAL CHARACTERISTICS AND MECHANICS OF CERTAIN DEPRESSED-CENTER STONE RINGS IN NORTHWESTERN GREENLAND

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Detailed textural analyses of two rings and excavations of others revealed stones concentrated at the surface and in the borders by congeliturbation and fines concentrated centrally near the frost table by eluviation and congelifraction. Borders extend downward to perhaps 2½ feet and generally grade vertically and laterally from stones to fines. Measurements on 687 cobbles in the 0- to 6-inch layer of a ring revealed pronounced radial orientation.

Observations of the water table at 17 points within one ring showed that ground water migrates through the borders, percolating through a mesh from high to low end (slope $< 1°$). Within one ring 7000 readings from 76 thermocouples indicate the sequence of thaw and freeze-up results in (1) a gutter forming under the borders in early spring, (2) topographic reversal of the frost table with a basin under each mesh, (3) freeze-up from all directions toward the center of a mesh.

Variations in insolation with a negative thermal gradient from the permafrost result in frequent fluctuations in the position of the frost table. Congelifraction is most effective here, and sorting and radial orientation occur in small movements of individual stones, by the crystallization of ice growing between stones, and fluctuating frost table. During freeze-up moisture within a mesh migrates to freezing surfaces in all directions, but primarily downward and laterally to form a nearly uniform layer of ice on the frost table. The growth of this layer is responsible for most of the movement detected by precise surveys.

USE OF THE TERM "SCHODACK FORMATION" IN WASHINGTON COUNTY, NEW YORK

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The Cambrian sequence in Washington County shows the Bomoseen Grit overlain by purple and green slates with associated quartzites, nodular limestones, and limestone conglomerates succeeded by black shales with associated limestones and brown-weathering sandstones locally with limestone breccia. This black shale unit has generally been correlated with the Schodack Formation of Columbia and Rensselaer counties, New York. The type section of the Schodack Formation, in the railroad cut 2 miles south of Schodack Landing, exhibits green slates with nodular limestones and limestone conglomerates containing the *Elliptocephala* fauna. These beds are overlain conformably in the same cut by black shales and interbedded brown-weathering sandstones, two of which contain limestone breccia. Cross-bedding in the sandstones indicates that the section is not inverted. This section is

comparable with the Washington County section, the homotaxial equivalent of the fossiliferous limestone at Schodack is in the upper part of the purple and green slates with its limestone conglomerates. Thus, the term Schodack is inapplicable to the "Cambrian black shale" of the Slate Belt.

STRATIGRAPHY OF THE SILURIAN QUARTZITES AND CONGLOMERATES IN NEW JERSEY

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The Shawangunk Conglomerate of the New Jersey Valley and Ridge Province is Medinan and possibly Niagaran in age. The Green Pond Conglomerate of the New Jersey Highlands Province to the east was correctly thought in the past to be its equivalent. Both formations rest unconformably on underlying rocks and were subjected to Appalachian and possibly Acadian deformation. The Green Pond Conglomerate is preserved only in the downthrown sides of Triassic normal fault blocks. The two formations are similar lithologically and consist of well-indurated quartzites and quartz-pebble conglomerates with subordinate amounts of shales and siltstones. The Shawangunk Conglomerate contains a sparse annelid-eurypterid-fish assemblage, while the Green Pond Conglomerate is unfossiliferous.

Decreasing grain size to the west and consistent cross-bedding dip direction in both formations point to an eastward provenance, which can be divided into four terranes on lithologic basis. The presence of euhedral zircon in the lower 500 feet of Shawangunk Conglomerate and its absence in the Green Pond Conglomerate suggest sediment by-passing in the latter area. Continued deposition resulted in a maximum 1800 feet of Shawangunk Conglomerate and 1500 feet of Green Pond Conglomerate.

The deltaic shape and intermediate position of the sedimentary body with respect to the craton suggest deposition in an exogeosyncline. The westward-lying Medinan shore line as well as lithologic characters, especially mudcracks, in the Shawangunk Conglomerate indicate a broad gently sloping alluvial-plain environment for the two formations.

The establishment of stratigraphic equivalency of both formations warrants the elimination of Green Pond Conglomerate as a formational name.

REBOUND PROBLEM IN THE PIERRE SHALE AT OAHE DAM, PIERRE, SOUTH DAKOTA—PART II

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This part of the paper presents the history and a description of the rebound, a summary of observed movements, pertinent physical properties of the shale, and a discussion of the factors contributing to the movements.

Excavation for the Outlets Works Stilling Basin was substantially completed in November 1954. Irregular differential movements up to 0.8 foot were observed in January 1955 along fault planes in the bottom of the excavation. Instrumentation was installed to measure movements at and beneath the surface of the bottom of the excavation and the side slopes.

Vertical and horizontal movements occurring in the bottom of the excavation subsequent to January 1955 equaled or exceeded the initial displacements but occurred at slower, diminishing rates. The vertical movements occurred largely in the upper few feet of the shale; deeper movements were relatively small and fairly constant. No significant side-slope movement was observed.

The Pierre Shale in the bottom of the excavation is highly bentonitic, has a swell potential of approximately 3 per cent, and can develop loads as high as 10 tons per square foot when swell is prevented.

Initial movements were largely elastic because of load removal. Subsequent movements were probably plastic adjustment due to changed stress distribution after load removal and expansion of the shale by absorption of water. The movement of the shale along fault planes resulted in an irregular pattern of differential rebound which necessitated review of the design of the Stilling Basin structures.

SCHOLARSHIP IN GEOLOGY

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The ideal scholar has been described as one who "can study, think, teach, and write," and is therefore as much researcher as teacher. Geologists in government and industry perform much research, but many potential teachers among them are afforded little opportunity to teach; the proportion of teachers who have time for research seems to have declined, and increasing enrollments is expected to lower the proportion. The functions of schools, industry, and government are different but they are all jeopardized as the tasks of teaching and research are divorced. In contrast to the United States, in some European and Latin American universities the faculties include professional men who actively seek an opportunity to devote part of each week to teaching duties; large introductory courses find favor as well as advanced courses for small groups of selected students. The stimulus of the academic environment is the principal reward for the professional man, but the prestige of the affiliation and the sense of accomplishment of the discharge of a cultural responsibility are added recompense. Participation in teaching by research scholars in industry and government offers rewarding opportunities for the research organizations and the universities alike.

CHEMICAL COMPOSITION OF THE PIERRE SHALE AND EQUIVALENT ROCKS OF LATE CRETACEOUS AGE, GREAT PLAINS REGION

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New chemical analyses are available for 17 samples of marine shale as part of a recently inaugurated and continuing study of the geochemistry of shale. Seven analyses are from the *Baculites obtusus* zone (Mitten Black Shale Member of Pierre Shale and the corresponding middle part of the Claggett Shale) and 10 are from the *Baculites compressus* zone (middle to upper part of Pierre Shale and the corresponding lower three-fourths of the Bearpaw Shale.

The average composition (and standard deviations) of the 17 samples of shale is SiO_2—59.68 (3.59), Al_2O_3—15.40 (1.56), Fe_2O_3—4.56 (1.12), FeO—0.96 (0.66), MgO—2.11 (0.49), CaO—1.52 (1.15), Na_2O—1.09 (0.43), K_2O—2.49 (0.27), H_2O minus—3.73 (1.12), H_2O plus—4.77 (0.86), TiO_2—0.60 (0.06), CO_2—0.87 (1.34), P_2O_5—0.15 (0.05), SO_3—0.85 (0.98), Cl—0.01, F—0.07, S—0.21 (0.19), MnO—0.19 (0.41), BaO—0.08 per cent.

This composition is very similar to the compositions of other kinds of shales and to that of "average" shales. The K_2O contents of samples of the Pierre (2.49), Devonian "shales" (3.70), and Precambrian "shales" (3.79), and the Al_2O_3 contents (15.40, 19.65, and 17.24, respectively) differ more than the other major constituents. X-ray data indicate that montmorillonite predominates in samples of the Pierre. Illite is generally the predominant clay mineral in older shales. The differences in K_2O and Al_2O_3 contents probably result from such mineralogical differences rather than from any changes in the geochemical cycle of K and Al with time.

GEOLOGIC CAUSES OF STRENGTH IN SOILS

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The strength of what the engineer calls soil and the geologist calls unlithified sediment depends upon geologic characteristics of the soil. Soils are of two types: (1) clastic or noncohesive soils, composed mainly of clastic particles of sand or silt size, in which strength depends primarily upon friction between grains and is influenced by such factors as load; water content; degree of saturation; density; and roundness, surface texture, size distribution and packing of constituents; and (2) plastic, or cohesive soils, containing some or much plastic material of clay composition, in which strength is influenced by forces between clay particles in the moist state. The principal variables that affect strength of cohesive soils are water content, sand-clay ratio, grain size, clay type, temperature, and time. In the present investigation individual effects of these factors have been studied by shear vane tests of synthetic mixtures of saturated sediments of known composition. In cohesive soils strength has been found to increase with decreased water content, increased percentage of clay, decreased grain size (increased surface area), decreased temperature (viscosity effects), and time (thixotropic and diagenetic effects). For given water content, montmorillonite clays are considerably stronger than illite clays, which in turn are slightly stronger than kaolin clays. Hydrogen clays are stronger than sodium clays. In sand-clay mixtures (clastic-nonclastic combinations of given composition) strength increases with increased fineness of the clastic particles, and rate of increase in strength increases as grain size diminishes.

HYDROTHERMAL STUDIES IN THE SYSTEMS $NaAlSi_3O_8$ (ALBITE)-H_2O-HF AND GRANITE-H_2O-HF

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Albite melts at 810°C. in the presence of water vapor at 40,000 psi. The addition of 2 per cent HF to the system lowers the temperature of beginning of melting, at the same pressure, to 650°C. an additional lowering below that for water alone of 160°C. The temperature of complete melting is lowered from 810°C. to 770°C. at the same pressure. A 4 per cent solution lowers the temperature of beginning of melting to 620°C., and an 8 per cent solution produces melting at approximately 595°C. at 40,000 psi total pressure. The temperature of complete melting is 700°C. with a 4 per cent solution and 685°C. with an 8 per cent solution.

Experiments are now under way on granite compositions, and a reasonable extrapolation of preliminary data indicates that melting can be expected at temperatures as low as 550°C. at 80,000 psi. This is equivalent in pressure to approximately 12 miles depth in the earth's crust, and with a geothermal gradient of 50°C. per mile the appropriate temperature for melting would be reached at 11 miles depth.

It is therefore suggested that magmatic liquids exist at all times in geosynclinal areas where the gradient is on the order of 50°C. mile and the composition approaches that of the average granite. The origin of granite and metamorphic rocks will be discussed in the light of these experimental results.

REBOUND PROBLEM IN THE PIERRE SHALE AT OAHE DAM, PIERRE, SOUTH DAKOTA—PART I

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This part of the paper is a review of the influence of geological factors on a rebound problem, which occurred during excavation of the Outlet Works Stilling Basin, Oahe Dam, on the Missouri River.

The Pierre Shale is the foundation material at the dam site. It is a compaction shale derived from clays and silts of Cretaceous age which were consolidated by an overlying sediment load of 80 to 100 tons per square foot.

Before the Illinoian glacial stage the area was drained by eastward-flowing streams, and erosion by this drainage system removed at least half the original overburden load. The advance of the glacier dammed these streams forming lakes which spilled over low divides and cut connecting channels to form the Missouri trench. The trench was cut rapidly and reached maximum depth during Sangamon interglacial stage. The Iowan glacier crossed the Missouri, and the Tazwell ice sheet reached the Missouri.

These repeated cycles of loading and unloading, combined with removal of lateral support by downcutting of the river, stressed the shale walls adjacent to the trench causing extensive slump faulting. The resulting fault pattern is haphazard and complex. Faulting due to regional deformation is not evident at the site.

During excavation for the Stilling Basin a maximum of 12 tons per square foot of overburden load had been removed, and normal rebound was expected. However, differential rebound occurred along old slump fault surfaces creating an unusual problem.

LITHOLOGY OF UPPER TRIASSIC LOCKATONG ARGILLITE

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The Lockatong argillite consists chiefly of hard, massive, medium-gray to black, grayish-olive-green, dusky-red, and reddish-brown mudstone. There are also beds of gray dolomite, black carbonaceous shale, and gray siltstone and very fine-grained sandstone.

Massive gray to black argillite predominates in the middle of the formation; coarser-grained reddish-brown argillite predominates in the upper and lower parts.

Although the argillite appears massive and thick-bedded, it commonly is characterized by small-scale sedimentary structures: (1) thin-bedding and lamination, (2) graded bedding in some thin-bedded units, (3) cross-bedding in coarser-grained layers, (4) disturbed bedding consisting mainly of intraformational crumpling and brecciation, especially in the thin-bedded dusky-red facies, and (5) mud cracks and ripple marks in the reddish-brown facies.

Some analyzed samples of argillite are composed essentially of analcime and illite; others contain illite, feldspar, and quartz. The presence of analcime in samples from widely separated outcrops suggests that the mineral is authigenic.

Dolomite occurs in thin layers interbedded with gray to black argillite. It is also disseminated through most samples of argillite analyzed. In addition, minute crystals of calcite are present in both gray to black and dusky-red thick-bedded argillite.

Pyrite occurs along bedding planes of thin-bedded gray to black argillite and as nodules as much as an inch in diameter in massive black argillite.

Opal and chalcedony fill cracks and voids but are not common constituents of the argillite. In fact, its SiO_2 content is only about 46 per cent.

BERYL STUDIES $3BeO \cdot Al_2O_3 \cdot 6SiO_2$

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Beryl has been synthesized hydrothermally at temperatures from 500°C. to 850°C. at pressures from 15,000 to 30,000 psi using stoichiometric proportions of constituent oxides. The synthetic beryl was optically negative with $\epsilon = 1.569$ and $\omega = 1.566$. At 900°C. and above, beryl in the presence of H_2O decomposes slowly into phenacite and glass. Two natural beryls lost water plus other volatiles

(amounting to about a 2% weight loss) at approximately 790°C. They melted incongruently at approximately 1475°C. into liquid plus phenacite. Initial experiments indicate that beryl may be stable at super pressures of 30,000 atmospheres at 800°C. Attempts to synthesize a germanium beryl ($3BeO \cdot Al_2O_3 \cdot 6GeO_2$) have not been successful to date. A germanium phenacite ($2BeO \cdot GeO_2$) has been synthesized hydrothermally.

CENOZOIC GEOLOGY OF THE IONE QUADRANGLE, NEVADA

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Volcanic and associated sedimentary rocks of Cenozoic age underlie approximately 85 per cent of the Ione quadrangle, Nye County, Nevada. The volcanic rocks range in composition from rhyolite to olivine andesite. The following stratigraphic sequence has been established for these rocks in a field study for the U. S. Geological Survey:

Age	Unit	Thickness and Lithology
Quaternary	Unnamed	Thickness unknown. Olivine andesite
Pliocene (?)	Toyabe quartz latite	2000 feet; rhyolitic, quartz-latitic, dacitic welded tuffs, and associated rhyolites and andesites; 300–400 feet of olivine andesite, augite andesites, and augite-hypersthene andesites rest on top of the welded tuffs
Early Pliocene (?)	Oddie rhyolite	1000 feet; rhyolitic breccias, tuffs, and lavas
	—Unconformity—	
Late Miocene and Early Pliocene	Esmeralda formation	4000 feet; tuffs, breccias, occasional thin lavas, interbedded sedimentary rocks
	—Unconformity—	
	Unnamed	1000 feet; keratophyre, andesite, minor amounts of trachyte
Early Tertiary	Unnamed	1500–2000 feet; rhyolite lavas and tuffs, trachyte lavas and tuffs
	—Unconformity—	
Paleozoic to Mesozoic	Unnamed	Sedimentary and intrusive igneous rocks

The stratigraphic sequence in the Ione quadrangle can be correlated with sequences worked out in the Tonopah district and in the Round Mountain quadrangle. Rocks equivalent to the early Tertiary and the Esmeralda formations and the Toyabe quartz latite can be recognized over much of the Tonopah 1-degree quadrangle. In addition, correlation may be possible with sequences established in the Coaldale and Mina quadrangles.

RING-FRACTURE INTRUSION AND MINERALIZATION AT CLIMAX, COLORADO: A PRELIMINARY REPORT

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The Climax molybdenite deposit consists of two large and roughly concentric, dome-shaped stockworks in a complex of Precambrian crystalline rocks and Tertiary intrusive porphyries in the Ten Mile Range, central Colorado.

All porphyries in the mine area are mineralogically and chemically similar to Precambrian granites

which they intrude. Thus, where intensely altered, these rocks are difficult to distinguish; different interpretations of rock origin have resulted in different concepts of geologic setting. Recent studies indicate that, except where alteration is extreme, original rock types can be identified with reasonable confidence. The basic pattern of distribution now recognized is Precambrian country rock intruded by: (1) discontinuous and arcuate dikes of sheared, biotite-bearing porphyry that define a peripheral zone of ring-fracture intrusion, (2) an inner ring-dike of quartz—K-feldspar porphyry, and (3) a central stock of albitized granite (?) porphyry.

Both ore bodies are circular to ring-shaped in plan and arcuate in section;—i.e., generally similar to the ring-dikes—and were formed largely by a process of fracture filling. It is believed that recurrent ring-fracturing was responsible for development of zones of intensely broken ground that controlled the distribution of molybdenite; the term ring-fracture mineralization is proposed for this mechanism of ore emplacement. Zones of silicification and tungsten mineralization have a similar shape and origin.

Fracture patterns, distribution of Paleozoic sediments, and asymmetry of the upper ore body and its relation to a prominent fault (Mosquito) suggest that the upper ore body was tilted westward before formation of the lower ore body.

Structural counterparts of Climax may exist among the porphyry copper deposits.

PALINSPASTIC MAPS OF SOUTH-CENTRAL CALIFORNIA AND A NEWLY RECOGNIZED SEGMENT OF THE SAN ANDREAS RIFT

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Palinspastic maps of south-central California have been prepared, utilizing Hill and Dibblee's proposal that the Big Pine and Garlock faults have been offset by the right-lateral San Andreas fault from their original continuity as a single left-lateral rift. Restoration to Pleistocene involves reversing the San Andreas movement until the Big Pine and Garlock faults are in line, then reversing the movement on the Big Pine-Garlock rift, and results in considerable north-south extension locally. Furthermore, the Big Pine-Garlock restoration defines the former existence of a discontinuity in the San Andreas rift as it is now mapped. Assumption of any early Pleistocene or older San Andreas movement before the assumed Big Pine-Garlock shift demands the existence of an unrecognized San Andreas segment, once functional but now out of line and virtually dormant. The west boundary of the Mount Pinos block is in the proper location to be this rift. Field reconnaissance demonstrates faulting between the basement block and adjacent sediments of the Cuyama area, but whether it is an important rift is unclear because a young and unconformable gravel cover lies across most of the edge. Complexity of the Big Pine fault itself permits tentative acceptance of the proposed rift. Further restorations, to late Pliocene and late Miocene, were made by assuming and removing tens of miles of right-lateral shift on the San Andreas and San Gabriel faults.

NATURE OF THE ORE BOUNDARY AND ITS RELATION TO DIAGENESIS AND MINERALIZATION, URAVAN DISTRICT, COLORADO

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Detailed paragenetic and geochemical study of the vanadiferous uranium ores in many mines of the Uravan district, Montrose County, Colorado, shows a general pattern of subtle zoning along the boundary of ore bodies and a general diagenetic alteration of the ore-bearing sandstone. Several trace elements including lead, copper, zinc, selenium, cobalt, nickel, and silver tend to concentrate in thin zones along the ore borders. Rare minerals include ferroselite, clausthalite, descloizite, brackebuschite, and vanadinite.

In addition to vanadium and uranium, the ore contains a greater content of magnesium and iron

than does the barren rock. Dolomite, pyrite, and chlorite account chiefly for the excess magnesium and iron. Calcite is the dominant carbonate in barren rock. Ore border zones show several stages in the development of chlorite from mixed-layer mica-montmorillonite and mixed-layer chlorite-montmorillonite. Much solution and redeposition of silica characterizes the ore and the adjacent barren rock.

It is suggested that diagenetic changes, related to saline carbonate water with H_2S from the intrusive salt anticlines and to devitrification of volcanic ash, included dolomitization, chloritization, local clay alteration, leaching of ferric oxide and formation of pyrite, and formation of authigenic barite. Later, mineralizing solutions containing carbonate and H_2S intensified the above processes and deposited uranium and vanadium as well as many trace elements. Within large zones of diagenetic alteration, mineralization is controlled further by sedimentary structures and the distribution of organic matter.

STUDY OF THE GROWTH OF SEA-ICE CRYSTAL

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A single crystal of sea ice is shown to be composed of a series of 0.45-mm wide parallel platelets of pure ice separated by layers and pockets of brine. These layers of inclusions are always parallel to the basal plane (0001) of the ice crystal, and the exact distribution of brine in a given layer is a function of the temperature and salinity of the crystal. The origin of this platelike substructure is correlated with the occurrence of Tyndall figures in lake and glacier ice. Because of these brine layers the thermal conductivity of crystals of sea ice is usually greater perpendicular to the *c* axis than parallel to it.

When sea ice begins to form the initial discoid-shaped ice crystals assume a position of maximum shape stability at the surface of the ocean. Since the *c* axis is always perpendicular to the base of these discoids the resulting skim ice is composed of ice crystals with vertical *c* axis. A series of fabric diagrams show that, when the ice sheet is approximately 4 cm thick, the crystals with their *c* axes vertical have been completely wedged out by crystals with their *c* axes horizontal. Crystals with the latter orientation are favored since their direction of maximum thermal conductivity is parallel to the direction of maximum heat loss causing them to grow at a slightly greater velocity than the other crystals. This selective growth also causes the average grain size of the sea-ice crystals to increase with the thickness of the ice sheet.

CHANGE IN SOLUBILITY OF CALCIUM CARBONATE WITH TEMPERATURE AND CARBON-DIOXIDE CONTENT

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The solubility of calcite and aragonite in carbonic acid has been determined over a CO_2 concentration range from 10^{-4} to 10^{-3} kg moles/m^3 and a temperature range from 10°C. to 70°C. The measurements were made in the absence of a gas phase in a newly developed conductometric solubility apparatus. The temperature derivative of solubility of calcite at constant CO_2 concentration varies from -10^{-6} to -3×10^{-6} kg moles/m^3 °C., being a maximum for the highest CO_2 concentration and temperature. The CO_2 concentration derivative of solubility of calcite at constant temperature decreases from a value of 1 at very low CO_2 concentrations.

At low CO_2 concentrations, the solubility of aragonite is the same as that of calcite, within the experimental errors. At a CO_2 concentration of 10^{-3} kg moles/m^3, aragonite is about 11 per cent more soluble than calcite.

HYPOTHESIS CONCERNING THE ORIGIN OF STRUCTURES IN ARGILLACEOUS ROCKS

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Laboratory studies of clay-water systems and field observations of properties of argillaceous rocks suggest a relationship between the environment of deposition of such rocks and the origin of such structures as fissures, slickensides, mud cracks, and bedding or laminae.

Clay minerals in well-laminated argillaceous rocks, such as shales, are oriented with their longest dimensions more or less parallel to the bedding. These shales generally contain few slickensides, are relatively resistant to disaggregation in water, and generally contain the better-developed crystalline clay minerals.

In contrast, the clay minerals in poorly laminated or nonlaminated argillaceous rocks have no preferred direction of orientation. These rocks commonly contain an abundance of slickensides, break down readily in water, and generally contain a larger percentage of mixed-layer clay minerals than the well-laminated argillaceous rocks.

Diagenesis, or upgrading, of clay minerals in the proper chemical environments would take place more readily where the clay minerals are deposited with their *c* axes parallel, as in well-laminated shales.

The structures in the argillaceous sediments have important bearing on behavior of roof shales and underclays in mines and on other engineering aspects of argillaceous rocks.

PALEOGEOGRAPHY DURING DEPOSITION OF PENNSYLVANIAN SAND BODIES IN TENNESSEE

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Pennsylvanian sand bodies in Tennessee have two distribution patterns: (1) widespread blankets and (2) long, narrow, digitate masses.

Owing to erosion, no single sand body is now entirely preserved. However, it is thought that originally the Rockcastle and older blanket sands thickened southeastward and interbedded with unsorted carbonaceous sediments; northwestward, they abruptly thinned from about 100 feet to a few feet The younger Crossville and Wartburg sandstones pinch out abruptly southeastward and, through a thin equivalent, join with remnants of digitate sands farther southeast. Still younger sands are digitate with no (preserved) blanket equivalent.

It is believed that the lateral contact of blanket sands with unsorted carbonaceous sediment represents a shore line. Abrupt thinning is presumably due to a deepening of water. Digitate sands are thought to be submarine distributary channels where sediment-laden water was discharged at stream mouths down a sloping sea bottom into deeper water.

During deposition of the Rockcastle and older sands, a northeast-trending shore line is inferred near the southeast edge of the coal field. Most of the coal field was a shallow, agitated open body of water, but deeper, quieter water occurred in the northwest corner.

When the younger Crossville and Wartburg sands were deposited, this northwest area became a site of blanket sand deposition on the northwest edge of an asymmetric, deeper-water basin. A steeper southeast margin is inferred from the northwest-trending digitate sands developed there.

Still younger digitate sands extend westward far out into the coal field, which was probably the westward-sloping side of a much wider body of water.

CYCLIC SEDIMENTATION IN THE SALINA (SILURIAN) FORMATION OF SOUTHWESTERN ONTARIO

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The Salina Formation of Southwestern Ontario occurs on the eastern side of the Michigan basin. A typical rock section consists of approximately 60 per cent carbonates, 30 per cent evaporites, and 10 per cent shales; calcium carbonate and the evaporites are concentrated in the lower part of the section. The formation ranges in thickness from 350 to about 1350 feet; halite may compose an aggregate thickness of as much as 645 feet, whereas in some areas significant thicknesses are absent. Detailed examination of a core suggests the various lithologies occur in a rhythmic fashion although actual occurrences only approach the apparent cycle. The ideal cycle seems to be shale-shaly carbonate-carbonate-anhydrite-halite-anhydrite-carbonate-shaly carbonate-shaly carbonate and shale. The cycle supports the theory of evaporation for the origin of the carbonates and evaporites as chemical deposits in a restricted arm of a Silurian sea; general lack of fossils in the Salina supports an origin for the carbonates as deposits of a chemical process rather than an organic process. The small quantity of shale is considered significant in that, even though an arid climate may have been necessary for the precipitation of the evaporites and the carbonates, rainfall at infrequent intervals supplied rivers draining adjacent areas of low topographic relief from which shale and small quantities of sand were derived.

PLANT MEGASPORES FROM ILLINOIS COALS

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Preliminary investigation of plant megaspores from maceration residues of coals and carbonaceous layers of Upper Mississippian (Chester) and Pennsylvanian age, principally from Illinois, indicates that megaspores may be useful for correlation and in delineating coal-swamp heterosporous plant distribution.

Chester assemblages are dominated by spinose lageniculate spores and represent an arborescent lycopsid flora. Caseyville assemblages indicate a more diverse flora, dominated by spinose lageniculate and aphanozonate, auriculate, and zonate spores, by spores with fibrous coats, and by deltoid bladdered spores. Medullosan and sphenopsid spores are also present. Lower Tradewater assemblages are distinguishable by a great diversity of spore types, especially of the zonate spores, and by the occurrence and restricted range of at least one new genus. The upper Tradewater is characterized by smooth lageniculate spores, abundant medullosan spores, and by the lowermost occurrence of spores with lateral bladders. Carbondale assemblages are characterized by an abundance of smooth aphanozonate spores but, except for the absence of extreme forms of zonate spores, are otherwise similar to those of the Tradewater. McLeansboro assemblages, not investigated extensively, appear to be characterized by heavy-apexed, smooth lageniculate spores, smooth aphanozonate spores, medullosan spores, and by the rarity of zonate spores and spores with fibrous coats.

The differentiation of the lageniculate spores on the basis of slight ornamentation variations, the apparent restricted ranges of some spores, and marked variation in abundance of other spores permit a rough zonation of Upper Mississippian and Pennsylvanian coals.

FACTORS INFLUENCING EROSION OF A COHESIVE RIVER BANK

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Successive cross sections during the 5 years 1953–1957 reveal as much as 7 feet of lateral erosion of a cohesive river bank composed primarily of silt on a small stream (drainage area 4 square miles)

in Montgomery County, Maryland. The channel has not widened, because of progressive deposition on the opposing point bars. The observed sinuous channel traverses a grassy meadow nearly devoid of trees. Detailed measurements over a period of 2 years indicate several combinations of factors primarily responsible for the progressive recession.

Despite the occurrence of the highest flood of record in July 1956, winter erosion during December, January, February, and March accounted for approximately 85 per cent of the observed erosion. The maximum occurred during a bankful flow which attacked previously wetted banks removing 0.15 to 0.20 foot of sediment in several hours. Erosion was most severe at the water surface.

Cold periods associated with wetbanks and with frost action and accompanied by low rises in stage accounted for 0.6 foot of erosion in 6 weeks during the winter 1955–1956. Third in erosion effectiveness appeared to be a combination of moist banks and low rises in stage. Crystallization of ice and subsequent thawing, without benefit of changes in stage, also produced some erosion as did flashy summer floods even on hard dry banks. That the effect of frost action alone is minor is supported by data from North Carolina which show equally large volumes of sediment transported by winter flows in an area unaffected by frost.

WADENA GLACIAL LOBE, MINNESOTA

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The drift of the Wadena glacial lobe in west-central Minnesota reveals a fan-shaped drumlin field about 60 miles long. It was assigned by Leverett to an Iowan (?) ice lobe that moved east and north out of the Red and Minnesota river valleys. The writer suggests that movement was in the opposite direction (to the southwest) and designates the ice as the Wadena lobe of Cary correlation. The following relations support this major revision.

(1) A fan pattern of drumlins, much like that of the Green Bay lobe in Wisconsin, suggests an expanding rather than a constricting lobe.

(2) Elongate stones in 16 till-fabric analyses have preferred long-axis plunge to the northeast (up-glacier). This orientation fits a theory of glacier flow involving movement along flow planes dipping up-glacier.

(3) The curvature of the west and south margins of the drumlin field parallels a broad arcuate morainic complex, here considered the terminal moraine of the Wadena lobe (later overridden by the Des Moines lobe) rather than as the Altamont moraine of the Des Moines lobe itself (Leverett).

(4) Unlike the Des Moines-lobe till, the Wadena-lobe till lacks Cretaceous shale fragments. The Wadena lobe must have moved southeast from the Winnipeg limestone lowland, thence Southwest SW to form the drumlins.

(5) On the east, Wadena till is underlain, interbedded, but principally overlain by Cary tills of eastern source. The drumlin field is partially obscured on the east and north by younger Cary drift, and on the south and west by overlapping Mankato drift of the Des Moines lobe.

DISCREPANCIES BETWEEN OPTIC AXIAL ANGLES OF OLIVINES MEASURED OVER DIFFERENT BISECTRICES

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Discrepancies in 2V measurements of olivine made over different bisectrices have been recorded periodically, but they have not been explained. To compare measurements made over different bisectrices by both single- and double-axis methods a number of measurements were made on fresh,

unzoned olivines. The mean of single-axis measurements agrees closely with the mean of double-axis measurements, and no significant difference exists between single-axis measurements made over α and γ. In the double-axis measurements, however, a persistent difference exists; 2V measured over α is smaller than 2V measured over γ by about 2.5°. Since the conoscopic method was used, this difference is greater than can be accounted for by experimental error. The discrepancy may be explained if, for high angles of tilt of the universal stage, the observed angle is smaller than the true angle, and calculations indicate that refraction within the layers at the centre of the sphere could produce this effect.

The results emphasize the importance of using low angles of tilt of the universal stage whenever possible, and they demonstrate the nature and magnitude of the error introduced when high angles cannot be avoided.

Ab-An-H_2O, An-Or-H_2O, AND Ab-Or-H_2O AT 5000 BARS

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At 5000 bars H_2O pressure, high albite, anorthite, and high sanidine coexist with liquid + gas at 748°C., 1234°C, and 876°C., respectively. The Ab-An-H_2O system is of the "continuous-series type"; no unmixing relations are observed. The An-Or-H_2O system is of the "eutectic type"; the four-phase point (two feldspars + liquid + gas) lies at 845°C., where the bulk composition of the solid phases is An 12: Or 88. The limits of solid solution at 845°C. are less than An_2Or_{98} and about $An_{96}Or_4$. The Ab-Or-H_2O system is of the "minimum type"; the three-phase point (one feldspar + liquid + gas) lies at 695°C., where the composition of the solid phase is $Ab_{71}Or_{29}$. The solvus and solidus intersect at $Ab_{66}Or_{34}$ and $Ab_{42}Or_{58}$ and 698°C. This solvus is based on runs of one month, using only the results from glass-starting materials. Isothermal, isobaric sections in the Ab-Or-H_2O system were investigated at 710°C. and 720°C. with varying amounts of water: the liquids rich in feldspar components contain about 11 per cent H_2O; the aqueous gas phase probably contains about 1 to 2 per cent of the feldspar components; the maximum on the solvus, which at this pressure lies in a region where gas is prohibited, is at $Ab_{55}Or_{45}$ and 715°C. From the Bowen and Tuttle datum at 1000 kg/cm², the maximum of the solvus rises 14°/1000 bars. The crystalline products were not suitable for detailed optical or single-crystal X-ray studies.

Ab-Or-An-H_2O AT 5000 BARS

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The liquidus surface of the Ab-Or-An-H_2O system was investigated at 5000 bars. The projection of the four-phase (two feldspars + liquid + gas) boundary curve on the Ab-Or-An plane extends from $An_{12}Or_{88}$—845°C. to a temperature between 695°C. and 698°C. where it becomes a three-phase (one feldspar + liquid + gas) trough very close to the join Ab-Or-H_2O before terminating at Ab_{71}-Or_{29}—695°C. The fact that the liquids along the boundary curve are rich in Or and Ab has bearing on problems involving partial melting or metasomatism.

The assemblages in equilibrium with gas were determined at 770°C., 720°C., and 660°C.: the compositions of the two feldspars in equilibrium with liquid and gas were ascertained, and extent of the ternary solvus outlined. The range of temperature through which two feldspars may crystallize simultaneously from a given magma under equilibrium conditions is very limited. In general, the change of composition of the AbAn-rich feldspar with temperature is greater than that change for the OrAb-rich feldspar. No data are known for fixing the composition of ternary feldspars except along

univariant curves or at invariant points. In the latter cases, a point was fixed by observing the number and kind of phases about the point.

The four experimentally determined tie lines connecting coexisting feldspars are compared with those obtained from analyzed, natural, coexisting feldspars. The compositions of coexisting feldspars may yield specific clues to their temperature and pressure of formation.

CLAY MINERAL-CARBONATE RELATIONS IN SEDIMENTS

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Calcite and kaolinite are two common phases of devitrification of volcanic glass, which occurs abundantly in the sediments of the Peru-Chile Trench. Mineral phases found with calcite and kaolinite include, among others, chlorite and quartz, at least part of which is probably also formed post-depositionally.

The intimate association of calcite and kaolinite suggests chemical equilibrium between these phases, and presumably also with the surrounding water. Aside from the volatile components, this mineral pair is compositionally equivalent to the anorthitic component in the glass; anorthite must be unstable under the same conditions. Noteworthily, kaolinite formed extensively despite the probably high pH value at the site of devitrification.

Calcite-kaolinite-quartz form a stable mineral assemblage in a five-component system. The seven-component system, calcite-dolomite-chlorite-kaolinite, however, is a more realistic one. In the presence of free quartz and for arbitrary values of T, P, activities of CO_2 and H_2O, and bulk Fe: Mg ratio, only three phases should coexist. In the South American sediments the association calcite-chlorite-kaolinite is observed. The alternative, calcite-dolomite-kaolinite, is reported from the Niagara dolomite. No information is found on its supplementary assemblage, dolomite-kaolinite-chlorite; but abundant evidence exists for the calcite-dolomite-chlorite association in slates and other low-grade metamorphic rocks. Detailed petrographic data on these phases in the appropriate associations may lead to a better understanding of the diagenesis of carbonate-bearing argillaceous sediments and sedimentary rocks.

REGIONAL MEASUREMENTS OF CRUSTAL THICKNESS

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Crustal thickness has been determined for a number of regions in North America, using the phase velocity of Rayleigh waves from the Samoan earthquake of April 14, 1957. The existing network of seismograph stations supplied the basic data and made possible the identification of individual waves over a large part of the continent. The following results were obtained: Rocky Mountain region, 50–55 km; Basin and Range province, 40–50 km; western Great Plains, 40–45 km; central Interior Plains, 35 km; Canadian Shield, 35 km.

The results are roughly consistent with the Bouguer gravity anomalies in these regions and give support to a system of regional compensation of the Airy type.

The phase-velocity results are compared in a number of locations with results obtained in seismic-refraction measurements.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN LOS ANGELES CALIFORNIA, APRIL 19–20, 1957

CORDILLERAN SECTION (GSA), PACIFIC COAST SECTION (PS), AND SEISMOLOGICAL SOCIETY OF AMERICA

CRETACEOUS FAUNULE FROM BAHÍA TORTUGAS, TERRITORIA SUR DE BAJA CALIFORNIA, MÉXICO

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A faunule of mollusks and well-preserved Foraminifera from sparsely fossiliferous pre-Miocene rocks of Bahía Tortugas indicates a Late Albian or Early Cenomanian age for at least part of a thick clastic sequence recognized over much of the Vizcaíno Peninsula and adjacent islands of west-central Baja California. Specimens of the ammonite *Mariella* provide the chief evidence in this determination.

Rocks of approximately the same age are known also in the Vizcaíno Desert and possibly along the northern Baja California Pacific coast. The Upper Albian or Lower Cenomanian Stage may be represented in pre-Campanian brackish and/or nonmarine sediments which overlie *Orbitolina*-bearing biohermal limestones and pyroclastics in the northern coastal area.

GEOLOGIC INVESTIGATION FOR BREAKWATER STONE IN THE HALFMOON BAY AREA, CALIFORNIA*

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Investigations for a breakwater at Halfmoon Bay by the San Francisco District, Corps of Engineers, U. S. Army, was started in 1946 and has continued intermittently to the present. The breakwaters are estimated to require about 800,000 tons of stone ranging from 14 tons to small-gravel sizes.

Halfmoon Bay is in the middle Coast Ranges of California about 16 miles south of the entrance to San Francisco Bay and west of the Montara Mountain granitoid fault block but separated from it by a wave-cut terrace developed in marine sediments and overcapped by terrace deposits. The block is bounded on the east by the San Andreas strike-slip fault and is cut by northwestward-trending major and minor faults as well as by many cross faults. Part of the investigations included areal geologic reconnaissance of the entire area, four seismic surveys, diamond-core drilling of four sites, quarry test shots at one site, laboratory tests, and petrographic analyses of representative samples.

Three sites were drilled in the Montara quartz diorite. Samples from depths of 100 feet showed severe effects of faulting, weathering, and micro-fracturing of the mineral grains. One site was drilled in the Vaqueros Sandstone Formation. The rock has low specific gravity and is badly fractured and weathered. Oil was present on many of the fractures in the core.

To date, it appears that only the smaller-size breakwater stone can be produced locally.

K-FELDSPAR CONTENT OF JURASSIC AND CRETACEOUS GRAYWACKES OF THE NORTHERN COAST RANGES AND SACRAMENTO VALLEY, CALIFORNIA

Edgar H. Bailey and William P. Irwin
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The Coast Ranges north of Healdsburg and south of Garberville, California, consist chiefly of Jurassic and Cretaceous graywackes and shale, accompanied in some areas by greenstone, chert, and schist, and generally assigned to the Franciscan Group; however, reconnaissance mapping by W. P.

* Presented with permission of the District Engineer

Irwin and D. B. Tatlock indicates that they are divisible into three major units trending parallel to the coast line. In the adjoining Sacramento Valley, other sequences of graywacke and shale that are the same age as at least part of the Coast Range units consist of the Knoxville Formation, Shasta Series, and lower part of the Upper Cretaceous strata. Estimates of the K-feldspar content made after etching and staining several hundred graywacke specimens with sodium cobaltinitrite indicate the following:

(1) Graywackes in a coastal belt extending inland nearly to U. S. Highway 101 contain 1-35 per cent K feldspar, and most contain more than 5 per cent.
(2) Most graywackes in a central belt, associated with greenstones and chert, and thus similar to the Franciscan of San Francisco Bay area, contain no K feldspar or only a trace.
(3) Meta-graywackes in the eastern belt of the Coast Ranges contain no K feldspar.
(4) Graywackes in the Knoxville Formation in Sacramento Valley contain from a trace to 2 per cent K feldspar.
(5) Graywackes in the Shasta Series contain from a trace to 35 per cent.
(6) Graywackes in the lower part of the Upper Cretaceous in Sacramento Valley contain 1-50 per cent K feldspar.

MUD VOLCANOES NEAR BRANSCOMB, MENDOCINO COUNTY, CALIFORNIA

Edgar H. Bailey and Donald E. White
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In the northern Coast Ranges of California 6 miles west of Laytonville, Mendocino County, there is a small, little-known group of active mud volcanoes. Most of these lie in a small basin on the crest of a spur ridge underlain by graywacke and shale similar to the Yager Formation described by Ogle (1953) in the Eel River Valley area 50 miles to the north. In the basin there are five miniature volcanoes about 4 feet high built up by the discharge of a thin mud from their vents; in the basin and in a second area 50 yards to the east there are several calderalike pools without appreciable rims. From one of the pools a mudflow descends several hundred yards down a canyon to a point about 175 feet lower. The mud and water are cold (62°-65° F.) and probably are rising continuously; the slow and irregular overflow is caused by the momentary lifting of the mud by escaping gas, which is probably largely carbon dioxide. The mud volcanoes and flows are in many respects scale models of some volcanoes and lava flows.

The mud volcanoes are only a little larger than when photographed by G. A. Waring before 1910, but when the writers observed them considerable mud was being discharged. Greater activity seems to have been started within the last few months before the writers' visit in October 1956.

An analysis of the water indicates a very high concentration of sodium (5400 ppm), bicarbonate (14,500 ppm), and boron (530 ppm).

POSSIBLE HIGH SHORE LINES OF A PLEISTOCENE LAKE IN EASTERN MOJAVE DESERT, CALIFORNIA

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Topographic benches, green sediments, and sand ridges that occur in the eastern Mojave Desert are interpreted as features of a Pleistocene lake. At Mesquite Springs, south of Crucero, the upper of two terraces that curve around low hills is at an altitude of 1111 feet, and the lower one is at an altitude of 1096 feet. Granitic bedrock is rough above and polished below a wave-cut(?) ledge at 1096 feet. Southeast of Soda Dry Lake, two sand ridges at about 980 and 955 feet respectively are believed to represent ancient beach deposits. At both localities green lacustrine (?) sediments occur just below the lower lines.

These features lie well above the 946-foot altitude of the spillway of Lake Mohave (Thompson,

1921), which filled Soda Lake and Silver Lake basins and overflowed northward into Death Valley. If this spillway had been lowered before the filling of Lake Mohave or if the newly discovered features have been elevated by faulting or regional tilting since their development, then the inferred lake could have been restricted to the Soda Lake and Silver Lake Basins. Otherwise, it must have inundated the spillway and filled Death Valley, covering an area of about 1500 square miles. No shore lines have yet been found at these altitudes elsewhere in the Soda Lake and Silver Lake basins or in Death Valley, but more intensive search may reveal them.

AFTERSHOCK SEQUENCE OF THE KAMCHATKA EARTHQUAKE OF NOVEMBER 4, 1952

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Aftershock epicenters of the Kamchatka earthquake of November 4, 1952, are distributed over an area approximately 930 km in length by 200 km in width. Assuming that this distribution represents the active strain zone, the total average strain, average elastic energy, and average stress of the rocks before slip were 15.2×10^{-5}, 1.8×10^{2} ergs/cm^3, and 13.5 kg/cm^2, respectively.

The strain-release curve of the sequence has been constructed using observations principally from Uppsala and Kiruna. The data included more than 400 shocks with magnitudes 6.0 and over, which have occurred up to December 1956. The curve exhibits several segments each of the form $\Sigma J^{1/2} = A + B \log t$, where J is the energy, and t is the time measured from the time of the principal earthquake. The slope B changes abruptly at $t = 0.4$ day and at $t = 195$ days; the latter change is particularly pronounced. Moreover, this was accompanied by other evidence suggesting a change in mechanism. The coefficients B have almost the exact ratio of 1:2:5 in the three intervals 0–0.40, 0.40–195, and after 195 days. The aftershock activity shows a greater concentration at the ends of the assumed active fault segment, particularly at the northern end. The majority of the aftershocks have clear pP impulses generally 9–13 sec. after P, indicating that the foci were in or close to the Mohorovičić discontinuity. The strain accumulation and release for the time interval from 1897 to 1956 for the whole stress system, Kamchatka to northern Japan, shows a slow decrease with time. Comparison of the aftershock sequence with this graph leads to an approximate estimate of the possible duration of the sequence.

ENERGY IN EARTHQUAKES DETERMINED BY FIELD OBSERVATIONS

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In 1956 the writers reported to the American Geophysical Union that the strain just before three earthquakes studied could be represented by

$$v = M \cot^{-1} \alpha x$$

where v is the horizontal displacement, and x the perpendicular distance from the fault. This represents a departure from perfect elasticity. Benioff suggested that the departure is due to a lower rigidity near the fault. The writers find that the work done during the fault displacement at the time of the earthquake will equal the strain energy before it if the rigidity μ at a distance x from the fault is represented by

$$\mu = \mu_0 \left(\frac{\partial v}{\partial x}\right)_{x=0} \frac{1}{\dfrac{\partial v}{\partial x}}$$

where μ_0 is the rigidity at the fault.

GEOLOGY OF THE LOCKWOOD VALLEY AREA, KERN AND VENTURA COUNTIES, CALIFORNIA

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The Lockwood Valley area encompasses about 60 square miles. The oldest rocks—gneiss, schist, and hornfels—were derived from sediments invaded by granitic intrusions of probable Jurassic age. More than 2000 feet of marine Eocene sandstone and shale lies unconformably on the crystalline rocks and is overlapped by 8500 feet of Middle and Upper Tertiary continental sediments. The continental rocks include the Caliente and Quatal formations and two newly differentiated units. Coarse clastics comprise most of the section, but fine-grained lacustrine facies, basalt flows, and acidic tuff occur in subsidiary amounts. Extensive Quaternary terraces cap the Tertiary and older rocks.

The Caliente and one of the new formations are tentatively correlated with the Vasquez-Mint Canyon sequence 40 miles southeast, and it is suggested they were once more or less contiguous deposits, now separated by large lateral displacement on the intervening San Gabriel fault. This postulate is supported by similarity of sedimentary sequences and crystalline rocks in the two regions, by the age relations of the rocks, and by independent evidence of lateral movement on the San Gabriel fault.

Strong deformation accompanied and controlled deposition of post-Eocene beds. Faulting dominated, first in Middle Tertiary (probably block faulting), then in Late Tertiary and Quaternary with apparent strike-slip movements and thrusting. Moderate to gentle folds, most of them on northeasterly trends, developed during these movements.

BIOGEOCHEMICAL PROSPECTING FOR MOLYBDENUM

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Agronomists have demonstrated that the assimilation of metals by plants is affected by factors related both to the nature of the plant and to the soil chemistry. Previous studies have shown that metals are concentrated in certain plant organs and that the concentration varies with the season, plant type, and the age of the organ and plant. In biogeochemical prospecting, geologists have demonstrated that the effect of these factors can be reduced by systematic sampling. The factors related to the soil chemistry, such as soil pH, amount and kind of exchangeable material present, and the influence of other soil ions, however, cannot be controlled and should pose a serious problem in biogeochemical prospecting.

Plant samples collected over molybdenum-bearing deposits in three areas in California show that (1) plants growing over such deposits have an abnormally high molybdenum content, (2) soil pH did not affect the assimilation of molybdenum by plants, and (3) molybdenum may be useful as a pathfinder element in the search for tungsten and copper.

NEW PALEOCENE FORMATION IN THE CENTRAL COAST RANGES, CALIFORNIA

Robert R. Compton
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A sequence of heretofore unnamed and undescribed Paleocene sedimentary rocks of the central Santa Lucia Mountains, California, is particularly well displayed in Secs. 26 and 35, T. 21 S., R. 5 E., Junipero Serra quadrangle. The unit has a maximum thickness of about 5000 feet and consists of about equal parts of dark-bluish-gray mudstones, poorly sorted sandy siltstones, and various sandstones, many with granules and small pebbles. Scarce lenses of unsorted breccia and conglomerate may be intercalated with either sandstones or mudstones. Some mudstones and siltstones are mas-

sive, whereas some show thin ungraded laminae and cross-stratification; the sandstone beds, which are as much as 20 feet thick, are commonly size-graded. These rocks are underlain unconformably by upper Cretaceous beds that are commonly similar to them and are overlain unconformably by Oligocene and scarce Eocene rocks. Both macrofossils and microfossils indicate that the formation is Paleocene, and their ecology supports structural and textural evidence that the sediments, moved by currents from the east and northeast, accumulated rapidly in a shallow nearshore basin.

STRATIGRAPHY AND CORRELATION OF THE PERMIAN NOSONI AND DEKKAS FORMATIONS, SHASTA COUNTY, CALIFORNIA

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At the type locality along Nosoni Creek the Nosoni Formation consists of 16,200 feet of basic pyroclastics, flows, and interbedded sediments. The lowest member, conformably overlying the McCloud Limestone, is about 150 feet of black, medium-bedded chert. The second member is 1495 feet thick and is primarily of bedded green tuff, tuffaceous conglomerate, and sandstone. The third member is 3265 feet of purple medium-bedded or massive tuffaceous conglomerate, tuffaceous sandstone, tuff breccia, fissile red shale, and black fossiliferous shale. The fourth and highest member is 1440 feet thick and consists largely of black medium-bedded silty shale, which is richly fossiliferous in many places. Andesitic flows occur throughout the formation.

The Dekkas Formation is here restricted to the 3840 feet of green massive tuff breccia, tuffaceous conglomerate and sandstone, minor basic flows, black cherty shale, and chert overlying the Nosoni Formation. In Nosoni Creek the conformable basal contact of the Dekkas Formation is drawn at the top of the highest black shale below a thick sequence of massive green tuff breccia. The contact with the overlying Triassic Pit Shale is conformable. As originally mapped much of the type Dekkas at Dekkas Creek is the lateral equivalent of the type Nosoni.

Species of *Parafusulina* and productid brachiopods dominate the faunas of both the Nosoni and Dekkas formations. These fossils show both formations to be of early Guadalupian age. The Nosoni fauna has close affinities with the Word fauna and some similarity to the fauna of the Phosphoria Formation. No higher Permian fauna was recognized.

SOME FEATURES OF MUDFLOW DEPOSITS

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Examination of many unconsolidated upper Tertiary and Quaternary volcanic mudflow deposits in the Cascade Range and the Puget Sound lowland of western Washington revealed a number of common features. Among the more striking internal features are an abundance of euhedral mineral grains, a crude size gradation with coarser material at the base grading upward into finer at the top, innumerable small cavities that probably were formed by entrapped air, and much included wood. The deposits generally have a linear distribution that reflects the trend of the valley through which the mudflow moved, although wide lateral distribution is found locally in areas where the underlying surfaces were of low relief. Most of the mudflows have a nearly flat upper surface, and where confined within a valley the deposits commonly occur as fill terraces along the valley sides. Exceptional thicknesses of mudflow deposits may occur in "backwaters" developed upstream from valley constrictions. Some of the mudflows examined conformably overlie soil profiles, volcanic ash beds, peat, and other easily eroded sediments, suggesting that mudflows have little or no erosive power on low gradients.

Many of the features associated with volcanic mudflows also have been found in mudflows that originated in a semiarid environment, and some features, such as cavities and graded size distribution, might also occur in till-like deposits that originated as mudflows from a glacier.

SANTA YNEZ RANGE NEAR SANTA BARBARA, CALIFORNIA

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The eastward-trending Santa Ynez Range in the vicinity of Santa Barbara and the adjacent coastal area exposes a continuously deposited sedimentary series totalling about 21,000 feet. This series consists of 3000 feet of upper Cretaceous, 10,000 feet of Eocene, 3000 feet of Oligocene, 2000 feet of lower Miocene clastic sediments (all marine except the Oligocene, which is terrestrial), and 3000 feet of middle and upper Miocene marine siliceous shales. Unconformably overlying this series on the coastal area is 0-3000 feet of Plio-Pleistocene littoral and terrestrial sediments.

The Santa Ynez Range is essentially a southward-tilted block elevated obliquely on the Santa Ynez fault at its northern base. The sedimentary series exposed in this block dip regionally south. Several northwestward-trending folds in the western part of the mountains are attributed to left-lateral drag movement on the Santa Ynez fault. In the western part of the area this fault is composed of two branches, one a southward-dipping reverse fault, the other a high-angle fault with possible left-lateral (?) displacement. Farther east it becomes a single steep fault with probable oblique-slip movement, and along a 4-mile segment Franciscan rocks have been squeezed up as a plastic mass, and the adjacent strata in this part of the range are overturned southward.

In the area north of the Santa Ynez fault the Cretaceous and Eocene formations are overlapped northward by Miocene formations, and all are strongly compressed into folds with axes trending north of west.

DEPOSITION OF MERCURIC SULFIDE AT AMEDEE HOT SPRINGS, CALIFORNIA

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Preliminary studies at Amedee Hot Springs, on the eastern shore of Honey Lake, California, indicate that mercuric sulfide is being precipitated from alkaline waters in and around the orifices of hot springs.

Hand specimens collected 20 feet from spring outlets show a thin layer of metacinnabar (about 1 mm) overlying a layer of cinnabar of variable thickness. Cinnabar occurs in thicker layers in specimens collected closer to the outlets; on rocks in the orifices of the hottest springs only cinnabar is present. The spring waters have the following characteristics: pH of 8.8; temperature at or slightly above the boiling point; high Na_2SO_4 (367 ppm); moderate NaCl (261 ppm); moderate SiO_2 (46 ppm); low $CO_3^=$ (48 ppm). The spring water possesses essentially the same composition now as in 1909. Water analyses by commercial firms revealed no mercury. Analyses designed to test for mercury have not yet been made. The presence of sulfur in the water in a form other than SO_4 ion was proved by the formation of sulfide on the surface of copper and silver strips immersed in the springs for several days.

The mercuric sulfide is being precipitated in response to changes in temperature, pressure, and compositional factors which are still under investigation.

LATE CENOZOIC VERTEBRATES FROM THE IMPERIAL VALLEY REGION, CALIFORNIA

Theodore Downs
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A new terrestrial vertebrate assemblage from the western Imperial Valley region was recovered from the Canebrake conglomerate (Dibblee, 1954) north of Vallecito Creek in the Anza Desert State Park, San Diego County, California.

Mammals so far recorded from the southwesterly dipping sediments bearing the fauna include: Vespertilionidae; Soricidae, small and large shrew; cf. *Scapanus*; Edentata; cf. *Sylvilagus*; cf. *Geomys*, an extremely large plains-type pocket gopher; Perognathinae; Dipodomyinae; Cricitinae; *Sigmodon*;

Neotoma; Canidae; *Spilogale*; cf. *Stegomastodon*; *Equus* (*Plesippus*); Camelidae sp., gigantic long-limbed camel; ?*Tanupolama*; *Tetrameryx*; ?*Euceratherium*; Cervidae. In addition there are many reptilian fragments, including turtles and lizards, and skeletal parts of a diving duck and a large crowlike bird.

Important vertebrate faunal correlatives appear to be: Curtis Ranch of southeastern Arizona, Bautista of southern California, and Irvington of the San Francisco Bay area; this indicates early Pleistocene age and probable early Irvingtonian Provincial age (Savage, 1951) for the fauna. Faunal resemblance is nearest the Curtis Ranch.

As mapped by Dibblee (1954), the Canebrake conglomerate grades downward into the terrestrial phase of the middle Pliocene Palm Spring Formation with continued gradation into the early Pliocene Imperial Formation; dating of the Pliocene formations is based on latest opinion by Durham (1954).

REINTERPRETATION OF THE TURTLEBACK FAULTS OF DEATH VALLEY, CALIFORNIA

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New evidence suggests that the turtleback faults at Copper Canyon and Mormon Point in the Black Mountains on the east side of Death Valley are not associated with the Amargosa thrust fault; they probably are normal younger faults. The turtlebacks are surfaces on anticlines (gently plunging northwestward) of Precambrian schist, gneiss, and carbonate rocks that are overlain by late Cenozoic fanglomerate and gravel. The turtleback faults, marked by 2–30 feet of gouge and breccia, separate these two rock units.

Precambrian rocks at the Mormon Point turtleback project southeastward into massive amphibolite rather than extend over Smith Mountain to the Desert Hound anticline on which the Amargosa thrust fault lies; hence the surfaces of these anticlines are probably different structural horizons. The turtleback faults are late Tertiary to middle or late Pleistocene in age, younger than the deposition of the siliceous volcanic rocks of the Black Mountains; the Amargosa thrust is middle Tertiary or older and predates the siliceous volcanic rocks.

Normal displacement along the Mormon Point turtleback fault is suggested by abundant subparallel normal faults in the hanging-wall rocks; some of these faults branch from the turtleback fault. The gently dipping Copper Canyon turtleback fault is continuous with the high-angle normal fault on the east side of Copper Canyon basin. The absence of subsidiary thrust faults and general lack of deformation other than by normal faults is more compatible with normal than thrust displacement on the turtleback faults.

SOIL CONDITIONS AND EARTHQUAKE DAMAGE: PRELIMINARY REPORT

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The paper brings to bear Japanese and American research and experience on the role of the soil in earthquake damage to buildings. The soil may contribute to resonance of building motion, to rocking and swaying on the foundation, and to diffusion of the building's vibration energy. Strong-motion earthquake data are reviewed, and the theoretical and experimental work on ground period, surface amplification, and the soil-structure system is summarized. Japanese and American soil conditions are compared. Promising current avenues of research are listed.

PELECYPOD *DOSINIA* IN LOWER OLIGOCENE OF CENTRAL CALIFORNIA

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As originally reported by B. L. Clark (1918), the pelecypod genus *Dosinia* occurs in the lowest beds of the Kirker Formation, beneath the Kirker tuff on the north side of Mount Diablo. The associated

fauna includes *Acila shumardi* (Dall), *Bruclarkia columbiana* (Anderson and Martin), and *Pitar clarki* (Dickerson); they place the containing beds in the Refugian stage of Schenck and Kleinpell (1936) and suggest a correlation with either the *Molopophorus gabbi* or the *Turritella olympicensis* zones of Durham (1944). According to the Weaver *et al.* (1944) correlation chart for the West Coast Cenozoic, beds of this age are to be correlated with the European lower Oligocene, either by the "megafossil" or the "microfossil" correlation. This is counter to the suggestion of Stewart (1930) that the first appearance of *Dosinia* coincided with the beginning of the Miocene and that the beds of the Walnut Creek-Mount Diablo area in which *D. mathewsonii* Gabb occurs should be considered Miocene rather than Oligocene, as concluded by Clark.

This species was originally identified as *Dosinia mathewsonii* by Clark and is externally very similar to it, except that the concentric sculpture does not seem to be quite so regular. Internally, however, in the right valve the nymph plate is more inclined from the vertical, the flattened area behind the posterior cardinal is slightly narrower, and the anterior lateral is slightly more posterior in position.

FOSSILIFEROUS AMBER OF CHIAPAS, MEXICO

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E. Böse in 1905 noted the occurrence of amber in Tertiary strata near the town of Simojovel, Chiapas, Mexico, and Kunz in 1884 described amber from "southern Mexico." In recent years amber has been reported from many localities south and east of Simojovel. In 1956 a rapid reconnaissance trip was made through the region, and five of these localities were examined. The occurrence of amber was verified at four localities, and fossils were collected from them. The various localities range in age from possible early Oligocene to middle Miocene. The youngest amber localities, of probable middle Miocene age, are near Simojovel. The associated fauna includes scutelloid echinoid *Abertella*. An outcrop near Jolpabuchil seems to be of similar age. Near Santa Catarina the beds contain *Lepidocyclina* and *Miogypsina* (?). An early Oligocene age is suggested. The gastropod *Orthaulax* occurs in the beds near Santa Lucia reported to contain amber and suggests an age near the Oligocene-Miocene boundary.

To date, about 75 species of insects, including ants, bees, beetles, caddisflies, cockroaches, dustywings, flies, moths, and thrips, have been recognized in amber from this region. Most, if not all, seem to be assignable to living genera on the basis of the preliminary studies. The insects are being referred to specialists for further study.

TERTIARY STRATIGRAPHY OF THE BLAIRSDEN QUADRANGLE, PLUMAS COUNTY, CALIFORNIA

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The area centers 50 miles northwest of Reno, Nevada. It is partly in the Sierra Nevada, partly in the Basin and Range Province, and wholly within the drainage basin of the Middle Fork of the Feather River. The Tertiary rocks have heretofore been only partially differentiated by H. W. Turner (Downieville Folio, 1897). The section is now established as follows:

Pleistocene-Upper Pliocene		1000 ft.	Lacustrine sediments
	Unconformity		
Upper Pliocene (?)	Warner Basalt	350 ft.	Olivine basalt lavas Equivalent: Tuscan Formation, Warner basalt

	Unconformity		
Lower Pliocene (?)		1350 ft.	Hornblende andesite mudflow breccia, volcanic conglomerate Equivalents: Kate Peak, Mehrten formations (?)
	Unconformity		
Lower Pliocene or Upper Miocene		700 ft.	Hornblende and pyroxene andesite volcanic conglomerate, and mudflow breccia Equivalents: Kate Peak and Mehrten formations (?)
	Unconformity		
Lower (?) Miocene		350 ft.	Welded sanidine rhyolite tuff; gravel at base
	Unconformity		
Oligocene (?)		550 ft.	Pyroxene and hornblende andesite mudflow breccia Equivalent: Alta andesite, Wheatland Formation
Eocene (?)		550 ft.	Basalt lava
	Unconformity		
Eocene	Auriferous gravels	500 ft.	
	Unconformity		
Pre-Tertiary	Various metamorphic and igneous rocks		

Five of the eight units extend westward across the Sierra Nevada. Possibly all but the lake beds are present in the Sierra Nevada. Each unconformity is marked by faulting and erosion. The last faulting marked the period of scarp formation and the elevation of the Sierra Nevada to its present height. Only then was southwesterly drainage from Nevada to the Sacramento Valley stopped.

EVIDENCE OF OVERTHRUSTING IN THE SAN FRANCISCO MOUNTAINS, BEAVER COUNTY, WESTERN UTAH

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The stratigraphic succession in the San Francisco Mountains has been mapped as conformable (U. S. Geol. Survey Prof. Paper 80). Recent study confirms the presence of an extensive overthrust, as suggested by Nolan and Hintze, necessitating a stratigraphic revision.

U.S. Geological Survey Professional Paper 80		*Revised Stratigraphy*
2000 feet Morehouse quartzite (Ordovician-Silurian)	=	3000 feet Prospect Mountain Quartzite (Precambrian (?)-Lower Cambrian)
conformable		thrust plane
		670 feet Ely Limestone (Pennsylvanian)
		fault
4000 feet Grampian limestone (Cambro ?-Ordovician)	=	1440 feet Pogonip Group, predominately Kanosh Shale (Ordovician)
		fault
		3440 feet limestone and dolomite (Middle (?)-Upper Cambrian) undifferentiated

The thrust plate of Prospect Mountain Quartzite underlies the crest of the mountains in the northern part of the area mapped and forms the bulk of the range farther north. Two small klippes remain at the southern end of the range.

Middle (?) and Upper Cambrian carbonates form the western base of the mountains. They are truncated by the overthrust and by faulting against Kanosh Shale. The Kanosh Shale is exposed beneath the overthrust on both flanks of the range. The Ely Limestone, which is not in contact with the thrust sheet, is faulted against questionable Cambrian carbonates in the southern end of the range. The Ely Limestone, the questionable Cambrian carbonates, and the klippes are separated from the main mass of sedimentary strata by a quartz monzonite intrusion.

The exposures beneath the thrust sheet on both sides of the range indicate that the overthrust has no root within the range and has an apparent horizontal displacement greater than the 4-mile width of the range.

ADDITIONS TO THE MICROVERTEBRATE FAUNA OF THE LANCE FORMATION

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In the 1956 field season, washing and screening techniques were applied to the upper Cretaceous Lance Formation near Lance Creek, Wyoming. The large assemblage of small vertebrates obtained includes: numerous fish remains, including several undescribed forms; fragmentary specimens of crocodilians, chelonians, and champsosaurs; small amphibians; several hundred isolated mandibles, maxillaries, and other skeletal remains of lizards; fragmentary bones of anurans and birds, both groups previously unrecorded from the Lance.

Many vertebrae have been referred to *Scapherpeton* Cope, a salamander and a growth series can be demonstrated. *Champs* Marsh, previously known from very few specimens, is here represented by 25 specimens, including several perfectly preserved dentary bones. Dentaries of a small form closely related to the heavily armored Eocene glyptosaurs were collected, but no osteoderms similar to those of the Eocene animal have been found. This may indicate that the glyptosaur group had not acquired heavy dermal armor by late Cretaceous time. *Gerrhonotus* (Anguidae) is represented in the fossil record for the first time.

Numerous other specimens may be referred to poorly known reptiles, such as *Lanceosaurus*, *Habrosaurus*, and *Parasaniwa*.

SEISMIC-REFRACTION MEASUREMENTS IN THE ATLANTIC OCEAN BASINS, IN THE MEDITERRANEAN SEA, ON THE MID-ATLANTIC RIDGE, AND IN THE NORWEGIAN SEA

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Seismic-refraction measurements in the western basins of the North Atlantic Ocean show that an average crustal section consists of ½–1 km of low-velocity sediments and 4–6 km of oceanic crustal rock in which the seismic velocity is about 6.5 km/sec. These layers are underlain by the mantle, which has an average seismic velocity near 8 km/sec. The measurements made in the eastern basins show a similar crustal section, but the velocity below the deep discontinuity appears to be lower (7.7–7.8 km/sec.).

Measurements in the Mediterranean Sea show only low-velocity sediments underlain by a refracting layer in which the average velocity is about 4.5 km/sec.

On the shallower parts of the Mid-Atlantic Ridge the sediments are underlain by two refracting layers with velocities averaging 5.6 and 7.4 km/sec. respectively. In the deeper areas only the sedi-

ments and the 7.4 km/sec. layer are found. Measurements in the Norwegian and Greenland seas show results very similar to those for the shallower areas of the Mid-Atlantic Ridge.

RADIOCARBON DATING OF WAVE-FORMED TUFAS FROM THE BONNEVILLE BASIN

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Radiocarbon dates have been determined for 10 wave-formed tufas from shore lines of pluvial Lake Bonneville and for 7 other specimens from sediments of the Lake Bonneville group. Among the tufas, the minimum determined age is 11,300 ± 300 years (W-409, W-439) from the Bonneville shore line, altitude 5150 feet. Maximum age, more than 32,000 years (W-410), is from the 4800-foot Provo level. Other Provo-level tufas range from 11,650 ± 450 (W-456) to 14,380 ± 500 years (W-458, W-491). Provo shore lines are essentially at the elevation of the outlet of Lake Bonneville. Four tufas from the 4500-foot Stansbury shore line range in age from 14,000 ± 400 (W-411, W-412), to 18,000 ± 1000 years (W-494).

Other age determinations are:

Number	*Sample*	*Altitude (feet)*	*Stratigraphic unit*	*Radiocarbon age (years before present)*
W-326	Peat from base of marl near Ogden, Utah	4650	Alpine (?) Formation	9925 ± 300
W-382	Marl above W-326	4650	Alpine Formation	12,960 ± 350
W-440	Re-run of W-326 (peat)	4650	Alpine Formation	10,260 ± 300
W-335	Wood in clay soil, Harrisville, Utah	4290	Post-Lake Bonneville Group	8330 ± 300
W-385	Shells in clay soil, Harrisville, Utah	4290	Post-Lake Bonneville Group	7720 ± 300
W-386	Plant stems in sand, Hooper, Utah	4235	Post-Lake Bonneville Group	9730 ± 350
W-445	Tufa, Pleasant View salient, Utah	4975	Alpine (?) Formation	14,030 ± 500
W-319, W-321	Core sample, composite of 12 feet; below Great Salt Lake	4142–4154	?	16,680 ± 300 16,850 ± 300

These data suggest that the Stansbury shore line is older than some higher stands and imply at least one stand at the Provo level before the Bonneville maximum. Other determined ages suggest a complex history of rising and falling lake stages.

EARTHQUAKES AND SURFACE FAULTING IN THE GREAT BASIN

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Faulting extending up to the earth's surface is relatively uncommon. However, during recent times many earthquakes in the Great Basin have been accompanied by faults. Some of these faults have large vertical displacement and extend for many miles. A few had undoubted strike-slip displacement.

The earthquakes and faults of 1872, 1876 (?), 1915, 1932, 1934 (two), 1950, and 1954 (four) will be discussed. Normal faulting occurred at the time of each earthquake. That of 1872 had large vertical and lateral movement. The lateral movement was right lateral on some faults and left lateral on at least one; in 1932 there was very small vertical displacement and small measureable lateral dis-

placement; one of 1954 had large vertical displacement and right lateral strike-slip movement in many places.

GEOLOGY OF THE CORONA SOUTH QUADRANGLE, NORTHERN PENINSULAR RANGES, CALIFORNIA

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The Corona South quadrangle lies in the northern part of the Peninsular Ranges and contains the northwest end of the Elsinore trough. The trough marks the trace of the Elsinore fault zone which trends northwesterly across the center of the quadrangle. The Chino fault diverges north-northwesterly from its apparent junction with the Elsinore fault near the eastern margin of the quadrangle.

The oldest rocks, Triassic Bedford Canyon metasedimentary rocks, occur mainly in the Santa Ana Mountains southwest of the Elsinore fault where they have been intruded by late Mesozoic plutonic rocks of the southern California batholith and in places are unconformably overlain by Jurassic (?) volcanic rocks. Northeast of the Elsinore fault is a succession of sedimentary rocks, several thousand feet thick, which includes rocks of Late Cretaceous through Quaternary age. These units are of types found to the west in the Los Angeles Basin.

The dominant structural features include the Elsinore and Chino zones of high-angle reverse faults and a synclinal trough extending from Santa Ana River southeastward beyond Corona and parallel to the Elsinore fault zone to the southwest. The surface distribution of Cretaceous sedimentary rocks indicates a probable minimum vertical displacement of 1500 feet along the Elsinore fault southwest of Corona, whereas to the southeast a displacement of more than 5000 feet is suggested by the difference in elevation of the basement complex on opposite sides of the fault. Large lateral displacement cannot be demonstrated in the quadrangle. In the Corona area the Elsinore trough is probably a faulted syncline.

EFFECTS OF GROUND ON SHAKING IN EARTHQUAKES RECORDED NEAR PASADENA, CALIFORNIA

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Local variations in earthquake damage depend partly on effects connected with properties of the ground. To investigate effects of such properties on earthquake records five east-west components of standard-torsion seismographs have been installed temporarily at about 20 locations around Pasadena in addition to the corresponding instrument at the Seismological Laboratory. Comparison of their records shows that the local thickness of the alluvium affects appreciably amplitudes and duration of shaking. At locations on deep alluvium, 1000± feet, the largest ratio of the maximum amplitudes to those at the Laboratory usually occurs for waves having periods near 1 sec. On records written on the campus of the California Institute or at the Huntington Library (both on nearly 1000 feet of alluvium) amplitudes of waves having periods of 1± sec. are commonly about five times as large as those written simultaneously at the Seismological Laboratory (on bedrock), and relatively strong shaking lasts about three times as long as at the Laboratory. However, waves having periods of more than 10 or less than ¼ sec. are recorded with approximately equal amplitudes at the three stations. At stations on alluvium a few hundred feet thick, the maximum-amplitude ratio occurs at wave periods near ½ sec. and on alluvium less than 100 feet thick at periods near ¼ sec. The duration of relatively strong shaking decreases correspondingly. Instruments on bedrock record amplitudes nearly equal to those at the Laboratory regardless of wave period.

DÉCOLLEMENT-TYPE OVERTHRUSTING IN SOUTH-CENTRAL IDAHO, NORTHWESTERN UTAH, AND NORTHEASTERN NEVADA*

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A large décollement-type overthrust of Paleozoic rocks over Precambrian rocks has been described (Misch, Hazzard, and others, 1953; 1954) in the Northern Snake Range, the Schell Creek Range, the Cherry Creek Mountains, and the Northern Ruby-East Humboldt Range in eastern Nevada. The present authors review four occurrences of a similar, and presumably the same, overthrust farther north:

(1) Albion Range, Cassia County, Idaho: The Albion overthrust, originally described (Anderson, 1931) as Precambrian crystalline rocks thrust over Carboniferous, actually represents thrusting of Paleozoic rocks over Precambrian.

(2) Raft River Range and (3) Grouse Creek Range, Box Elder County, Utah. Overthrusting described in the Raft River Range (Felix, 1956) is considered correlative with the Albion overthrust. The contact between Precambrian crystalline rocks and Paleozoic is tectonic, with no evidence for a "Raft River high" during Paleozoic time. On the west side of Grouse Creek Range, between Grouse Creek and Lynn, Paleozoic (Carboniferous?) rocks are overthrust on crystalline Precambrian. Relationships are partly concealed by Tertiary beds.

(4) Pequop Range, Elko County, Nevada: On the west side of the range, 5 miles south of U. S. Highway 40, Precambrian marbles and schists and mylonitized Precambrian marbles and Paleozoic carbonates crop out below essentially unaltered Paleozoic (in part Ordovician) rocks. The low- to medium-grade metamorphic rocks and the mylonites are interpreted as constituting a zone of tectonically mixed slices of Precambrian and Paleozoic rocks.

The thrust is probably mid-Mesozoic in age; it is post-Early Triassic (East Humboldt Range) and is believed to be pre-Early Cretaceous.

PLIOCENE ROCKS EAST OF STEWART'S POINT, SONOMA COUNTY, CALIFORNIA

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General region: northern California coast, northwestern Sonoma County, between Fort Ross and Gualala. Outcrop area: 22 miles long, 3½ miles wide, parallel to and 2 miles east of the coast line. Type locality: Annapolis quadrangle, Ernest Ohlson ranch, 5½ miles east of Stewarts Point, N½ sec. 3, T. 9 N., R. 13 W., M.D. Preservation: patchy, 500–1700 feet above sea level on hilltops, unconformably overlying Franciscan Formation. Thickness: 0 to about 200 feet. Lithology: sandstone, siltstone, and conglomerate similar to "Merced Formation," Pliocene, in Forestville-Sebastopol area, 14 miles to the southeast. Deposition: mollusk-bored wave-cut terraces and stacks buried beneath the formation show that, like the "Merced" to the southeast, it was essentially a shallow-water terrace deposit; sediments may have come from both the northeast and southwest, suggesting deposition in a northwest-southeast-trending embayment; there is no evidence that this joined the Forestville-Sebastopol Pliocene embayment to the southeast. Deformation: slight; shallow synclinal basin broken in places by renewed movement of pre-Pliocene normal, reverse, and strike-slip faults.

DIRECTION OF DISPLACEMENT IN WESTERN PACIFIC EARTHQUAKES

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In an earlier paper the writer showed that fault-plane solutions for earthquakes associated with a particular geographic feature have null vectors which lie parallel to the strike of that feature. Mc-

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Intyre suggested that this demands either (1) that the fault strikes be parallel to the feature or (2) that the displacement be perpendicular to the feature.

Solutions based on *P* only are ambiguous and in both the northwest and southwest Pacific published solutions could be interpreted in support of either possibility. Kogan produced 21 solutions for earthquakes in the northwest Pacific. These solutions have used *S* and are unambiguous. In no case do they support possibility (1). The displacements tend to be parallel to the northern Marianas; elsewhere they are nearly perpendicular to the associated feature as suggested in (2).

With this as a guide it is possible to select from the two possible planes obtained in earlier published solutions the plane that gives displacement most nearly perpendicular to the feature. There is good agreement between the displacement so selected and Kogan's solutions. Displacements are inclined to the normals to the geographic features at angles of 15°–30°; the sign of the angle is consistent over most arcs but varies from arc to arc. An exception is the New Hebrides arc, for which the sign of the angle is opposite at the two ends of the arc.

The data support McIntyre, and, although possibility (2) is favored, possibility (1) cannot be eliminated, particularly in the southwest Pacific.

INCONSISTENT OBSERVATIONS IN THE FAULT-PLANE PROJECT

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The 65 solutions published in the fault-plane project of the Dominion Observatory, Ottawa, Canada, have been based on 2476 observations of *P* and 722 observations of *PKP*. Of these observations, 19.3 per cent have been inconsistent with the published solutions, but a small number of stations have contributed a high percentage of these inconsistencies. Applying a criterion of rejection to the data reduces the percentage of inconsistencies to 14 per cent. Considering that most stations have tried to co-operate as fully as possible in the program and have reported observations even if the arrivals were recorded only as emergent phases, this percentage seems satisfactorily small.

Because the circles represent the boundaries between zones of compression and zones of dilatation, it might be thought that a higher percentage of inconsistencies would occur close to the circle. The reverse has been found; the observations close to the circular boundaries are slightly more accurate than those remote from them.

The inconsistent observations show no significant variation with epicentral distance, except that the percentage of inconsistencies is high at the shorter distances. This is the effect of the crustal layers and had been anticipated.

There have been 282 observations of *PP* and 135 observations of *pP*. These phases have both been inconsistent 30 per cent of the time. This suggests that the reflected phases should be used with discretion.

RELATION OF SYMMETRY TO STRUCTURE IN TWINNING

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Twinning is a two-dimensional structural discontinuity, whose boundary structure is continuous with each of two crystals, so that stable bonding is satisfied in this two-dimensional region. In the third dimension, cross-boundary bonding is nearly but not perfectly satisfied.

The first condition allows relations by any symmetry operation of the boundary structure (not present in the crystal structure): one of 79 space groups in a two-sided plane. In these groups are 4 types of symmetry operations differing with respect to the plane, which reduce to 11 twin-point symmetries, and to 5 if the crystal is centric. Twin axes *3*, *4*, or *6* are as logical as *2*, although only perpendicular to the plane. Also *2* axes parallel to the plane lie at 90° (or 120°) to one another in some plane groups, and one of these axes may be irrational, although this "edge-normal" twin is structurally as stable as its corresponding rational-axis twin. Thus in plagioclase albite-Carslbad and Carlsbad

twins are equally common. Here both directions are atom rows of the boundary structure, which attains symmetry by a slight distortion in the pseudosymmetric (010) slice of the crystal structure.

The second condition is attained if the twin law corresponds to pseudosymmetry in the structure. Some pseudosymmetry includes exact coincidence of a certain proportion of atoms, and, if these constitute an equipoint set, there is "twinning by merohedry." Most twinned structures have no coincidence sites, and their lattices are only pseudo-continuous. But relative stability of twins depends on how nearly perfectly twin symmetry retains all atomic positions, and for this Friedel's index and obliquity of the lattice are only first approximations.

INTERACTION OF BUILDING AND GROUND DURING AN EARTHQUAKE

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Accelerograms recorded in the basement of the Hollywood Storage Building during the Arvin-Tehachapi earthquake of July 21, 1952, are compared with the grams recorded on the surface of the ground several hundred feet distant. The building, 10 stories in height and of reinforced concrete construction, is supported on piles in relatively soft alluvium. Spectrum analysis of the records shows that in the short direction (1-second period) of the building there was negligible coupling with the ground, but in the long direction (½-second period) an interaction did occur. The interaction is attributed chiefly to the fact that the length of the building approaches the wave length of the higher frequency acceleration components in the ground motion.

DRAINAGE EVOLUTION IN NORTHEASTERN MONTANA AND NORTHWESTERN NORTH DAKOTA

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The distribution of gravels and topographic considerations support suggestions by earlier investigators that the master streams of northeastern Montana and northwestern North Dakota formerly flowed northward across the present trench of the Missouri until diverted in the Pleistocene. The age of the pre-diversion drainage is not precisely known. The ancestral streams cross early Tertiary structures. It has been suggested that the streams are antecedent and pre-early Tertiary in age. However, middle or later Tertiary superposition from a high-level erosion surface seems possible.

Miocene-Pliocene (?) gravels along the ancestral valleys indicate that the streams date back at least to the latter part of the Tertiary. A high-level gravel of possibly Oligocene or Miocene age parallels Yellowstone Valley for long distances, suggesting that the Yellowstone may have followed approximately its present path across the area in mid-Tertiary time.

The ancestral Missouri, Yellowstone, and Little Missouri rivers were diverted to form the present Missouri probably in Kansan time. This is earlier than the date proposed for the glacial Missouri in South Dakota, but the dates are not necessarily contradictory. Little Missouri River was diverted again, by Iowan ice, and joins the Missouri 80 miles farther downstream than formerly.

Both the Yellowstone and Missouri hug the right sides of their valleys and apparently did so in pre-Pleistocene time. Uptilting to the northwest or the effects of terrestrial rotation are possible explanations.

ENGINEERING GEOLOGY—AN AID IN ESTIMATING CONTRACT BIDS FOR HEAVY CONSTRUCTION

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Today, engineering geology is gaining recognition as an aid to the contractor in formulating preconstruction bids, although long ago accepted by the owner as an integral part of the site-selection,

planning-design, and construction phases. Bid prices on items involving geologic conditions or the procurement of natural materials are equally important to the contractor. Excluding the unforseen and human factors, geologic aspects are commonly the principal risk in a heavy-construction contract.

Sound geologic reasoning and "forecasts" can reduce the contractual risks by collaboration between the estimating engineer and an engineering geologist with construction experience. Collectively they can best establish bid prices for geologic items involved in open-cut excavations, underground excavations, sources of natural construction materials, and maintenance repairs caused by or associated with geologic conditions.

Some potential applications for contract bids are: establish classifications of excavation materials with quantities and characteristics; "forecast" and recommend concerning geologic conditions, adverse or favorable, that affect construction; reduce construction hazards and improve workers' safety; reduce contractual claims by suggesting contingencies clause for "potential" geologic problems or deviations from the owner's design; scrutinize the geologic "facts" supplied for alternate interpretations or a substitute source of natural construction materials. If no data are supplied, a contractor may conduct a limited geologic investigation.

Case histories are reviewed for bid items on a special tunnel in volcanic rocks beneath the channel at Seymour Narrows, British Columbia; open-cut excavations for drainages and highways in desert terrain of the Southwest; a construction materials source in a region of "soft" rock.

ENERGY RELEASE IN EARTHQUAKES

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The notion of applying methods of static elasticity to the study of energy differences in two states of a given structure was extended by Starr to yield the solution for problems involving the propagation of cracks in shear fields. This technique may be modified to include the solution of the problem of the energy release upon the introduction of a tear fault, such as the San Andreas fault, into an otherwise homogeneous medium subjected to a uniform shear stress. The idealized properties of such a fault are a structure elongated compared with its depth and a strike-slip motion along the fault. This configuration, by symmetry, may be imaged in the earth's surface, so that the problem is reducible to that of a strip fault of infinite length in an infinite homogeneous, isotropic, elastic medium. The medium is subjected to a uniform shear stress at infinity, and the shear stress is assumed to vanish upon the strip. This two-dimensional problem has a vector solution rather than a tensor one, and thus it has an analogue in the electrical problem of a perfectly conducting strip placed in a uniform electric field. The stress distribution and the relative motion throughout the medium, before and after faulting, can be obtained. For the case of the 1906 San Francisco earthquake, this model yields an energy difference of the shear fields before and after faulting of the order of 3×10^{23} ergs. This value must exceed the elastic wave energy.

STRONG-MOTION EARTHQUAKE PROBLEM IN INDIA

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Data are presented on the frequency, location, and magnitude of strong earthquakes in India. The larger-magnitude earthquakes (relative to those of smaller magnitude) are more frequent in India than in the rest of the world. Zones of relative seismic intensity are established. Special engineering problems are posed by the building materials and the types of construction used in India.

CRITICAL UPPER DEVONIAN FAUNULE FROM COCHISE COUNTY, ARIZONA

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Fossils obtained by C. M. Gilbert and R. C. Epis from a bed 12 feet above the base of the Devonian near the southeast corner, sec. 2, T.20 S., R.27 E. in the northern Swisshelm Mountains, Arizona, include abundant spiriferoid brachiopods closely resembling *Mucrospirifer argentarius* (Meek) and *Eleutherokomma jasperensis* (Warren). *Cyrtina* sp. is the most abundant element of the faunule, which also includes *Camarotoechia* cf. *C. saxitilis* (Hall), *Cranaena* sp., *Nervostrophia* (?) sp., *Nudirostra* sp., and a stony bryozoan. These fossils occur approximately 65 feet stratigraphically below *Devonproductus* cf. *D. vulgaris* Stainbrook and approximately 100 feet below corals characteristic of the Martin Limestone.

The spiriferoid faunule is considered early Late Devonian and is correlated with the *Spirifer argentarius* zone of Merriam (1940), the *Eleutherokomma leducensis* zone of Warren and Stelck (1950), and the *Nudirostra athabascensis* zone of McLaren (1954). The presence of *Devonproductus* cf. *D. vulgaris* Stainbrook, known from the Sly Gap Formation and Independence Shale, suggests that the Independence Shale fauna is younger than the widespread *Spirifer argentarius* fauna of western North America.

UPPER MISSISSIPPIAN PEERS SPRING FORMATION, LINCOLN COUNTY, NEVADA

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At Dutch John Mountain the Peers Spring Formation consists of a basal calcareous siltstone unit (approximately 140 feet), a middle black fissile shale unit (approximately 420 feet) with an included ledge-forming limestone, and an upper poorly exposed silty shale unit (approximately 460 feet). The overlying Scotty Wash quartzite includes approximately 75 feet of cliff-forming quartzite at the base followed by about 140 feet of less-resistant, finer-grained rock. These units, excepting the limestone, are also present at Peers Spring, but faulting prevents satisfactory measurement. The middle unit of the Peers Spring Formation closely resembles the bulk of the Chainman Shale at Ely, Nevada, but all three units together are lithologically similar to the White Pine Shale at Hamilton, Nevada.

A single identifiable specimen of *Cravenoceras hesperium* and a single specimen of *Rayonnoceras* were collected from the lower Peers Spring unit at Dutch John Mountain. The *Cravenoceras hesperium* fauna, including *Brachycycloceras*, is present in rocks of presumed similar stratigraphic position at Peers Spring. Westgate's (Westgate and Knopf, 1932) anomalous report of Lower Mississippian fossils in the Peers Spring Formation is apparently based on collections from a fault block of Bristol Pass Limestone at Peers Spring. Available paleontologic evidence thus suggests an Upper Mississippian age for the Peers Spring Formation and biostratigraphic correlation with the White Pine, Chainman, and Perdido formations.

TECHNIQUES OF ANALYSIS AND EFFECT OF CLAY COMPOSITION ON STRENGTH OF BORE-HOLE SAMPLES NEAR SAN FRANCISCO, CALIFORNIA

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In the course of an investigation of the fundamental geologic causes of strength of soils and soft sediments carried on under the auspices of a contract with the Office of Ordnance Research, the effect of clay composition upon the strength of 32 soil samples from three bore holes near San Francisco was studied. The depth of the bore holes ranged from 75 to 175 feet. The samples and data on strength were supplied by the Materials and Testing Laboratory of the California Division of Highways and

by the California Division of San Francisco Bay Toll Crossings. The percentage composition of different clay minerals in these samples was determined by special techniques of X-ray diffraction whereby the intensity of reflections of oriented soil samples was compared with the intensity of similarly processed samples of known mineral content. Difficulty was encountered because of the presence of several clay minerals in the samples. Illite was the main clay mineral, followed in order by montmorillonite, two types of chlorite, and kaolin. The samples richer in montmorillonite, containing 10–20 per cent montmorillonite, tended to be relatively strong for given water content. These prototype sediments thus corroborate the finding of similar strength experiments on synthetic mixtures of known clay composition.

TWO NEW INVERTEBRATES FROM THE CARBONIFEROUS OF NEVADA*

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Giant speriferoids from the upper Mississippian Diamond Peak Formation near Eureka, Nevada, are referred to *Dimegalasma* Cooper. They differ from *D. neglectum* (Hall) in possessing a smaller, less cyrtinoid pedicle beak, a greater width-length ratio, and much greater size.

A gyroconic nautiloid from the upper Mississippian White Pine Shale at the well-known exposure 5 miles north of Elko, Nevada, is referred to Flower's family Tetragonoceratidae. Pairs of nodes near the ventral shoulders differentiate it from *Welloceras* Flower, a lower Devonian genus.

GEOLOGY AND PETROGRAPHY OF THE SOUTH HALF, MT. ABBOT QUADRANGLE, CALIFORNIA

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The south half of the Mt. Abbot quadrangle, California, lies astride the crest of the Sierra Nevada about 25 miles west of Bishop. Its topography is rugged and is typical of glaciated terrain at high elevations elsewhere in the Sierra Nevada. The dominant trend of contacts and other primary linear elements is to the northwest. Regional jointing trends northeastward and northwestward and is most strongly developed in glaciated valleys. A long, narrow septum of Triassic (?)- Jurassic (?) metasedimentary and metavolcanic rocks occupies the center of the map area. Four plutons, consisting of gabbro, quartz monzonite, and biotite quartz monzonite, underlie about 90 per cent of the map area. A small flow of basalt rests on glaciated quartz monzonite. Alluvium and glacial debris form a thin cover on some of the basement rock.

Point-count analyses of the plutonic rocks indicate a considerable internal heterogeneity in the two larger masses, one of which resembles the Cathedral Peak "granite". However, plots of the modal compositions on triangular diagrams reveal that variations among hornblende, biotite, and sphene or magnetite generally bear a fixed relation to variations among potassium feldspar, plagioclase, and quartz. Hornblende is an essential constituent of one of the larger plutons and for all igneous rocks tends to increase as the color index of the rock increases.

SODIUM-RICH GRANITE FROM THE SOUTHERN PART OF PRINCE OF WALES ISLAND, ALASKA†

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A sodium-rich granite crops out over an area of about 3 square miles in the vicinity of Bokan Mountain on the southern part of Prince of Wales Island, southeastern Alaska. Cross-cutting relationships

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†Publication authorized by the Director, U. S. Geological Survey

show that, excluding dikes, the granite is the youngest crystalline rock in the area. The sodium-rich granite is largely surrounded by medium- to coarse-grained quartz monzonite and granodiorite, but in places it is in contact with metasedimentary rocks.

In places the granite is porphyritic, containing medium- and coarse-grained euhedral quartz phenocrysts and coarse-grained arfvedsonite (?) and acmite phenocrysts in a groundmass rich in medium- or fine-grained quartz and feldspar. Modal analyses based on the point-count method of Chayes show the rock to contain 30–52 per cent quartz, 28–47 per cent potassium feldspar, 7–13 per cent albite, 2–8 per cent arfvedsonite (?), 3–8 per cent acmite, and less than 1 per cent accessory minerals, chiefly zircon with lesser amounts of uranoan thorianite and uranothorite. The quartz phenocrysts range from 3 to 15 mm in length and have well-developed prismatic and rhombohedral faces. Some of the potassium feldspar is grid-twinned, and is probably chiefly microperthitic microcline. Sodium adularia cuts the older potassium feldspar. Albite occurs as subhedral crystals in the groundmass. Arfvedsonite (?) and acmite are generally closely associated and in places intergrown. The composition of the granite is further documented by chemical and semiquantitative spectrographic analyses.

VERTICAL DISTRIBUTION OF VELOCITY IN SALMON GLACIER, BRITISH COLUMBIA

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Six holes were drilled thermally in Salmon Glacier in the spring of 1956 by Granduc Mines, Ltd., to establish the elevation of the rock floor over the line of a proposed low-level access tunnel. Five of these reached what is believed to be the floor at depths ranging from 1625 to 2365 feet. The 1625-foot hole was cased and surveyed, first in May, then in August, to establish velocity at different depths.

Transit surveys showed a surface movement of 69.5 feet in 95 days. Inclinometer surveys showed that movement in this period diminished with depth to 65 feet at 875 feet, 60 feet at 1000 feet, and 50 feet at 1375 feet, and was 31 feet at the lowest level attainable in August—1560 feet vertically below the surface and about 45 feet vertically above the rock floor.

Velocity in feet per year approximates the formula, $42.1(1605 - depth\ in\ feet)^{1/4}$; the greatest known departure is at the 850-foot level, in which this formula yields an answer low by 10 per cent. The shear-stress–strain-rate relationship is not precisely determined but more closely resembles the relationship based on Glen's laboratory study of ice than the one based on field observations of ice flow on Jungfrau, Switzerland, made by Gerrard, Perutz, and Roch (1952).

An additional survey in 1957 is planned.

SIMPLE BOUGUER GRAVITY ANOMALIES AND THEIR RELATIONSHIP TO THE STRUCTURE OF THE NORTHWESTERN PART OF THE LOS ANGELES BASIN, CALIFORNIA*

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Measurements of the gravity anomalies in the northwestern part of the Los Angeles Basin were made with a Worden gravimeter at 840 stations in an area bounded on the east by 118° 15′ W. Long., on the north by the Los Angeles River, and on the west and south by the Pacific Ocean. The simple Bouguer values were then plotted and contoured on a map.

The pre-Upper Cretaceous metamorphic and igneous rocks that form the basement floor of the Los Angeles basin crop out above sea level at the northern and southern margins of the mapped area, but occur at depths probably exceeding 17,000 feet below sea level beneath the east-central part of the area. Faulted and folded Tertiary sedimentary rocks, mainly clastic marine rocks of Miocene and Pliocene age, overlie the basement rocks.

* Publication authorized by the Director, U. S. Geological Survey

A gravity maximum of plus 26 milligals occurs over the structurally high Palos Verdes Hills, and a gravity minimum of minus 79 milligals occurs over the structurally low trough of the deep part of the basin. Correlations exist between the other known major structures and the gravity anomalies.

LANDSLIDES OF THE PACIFIC PALISADES AREA, LOS ANGELES, CALIFORNIA

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Natural landslides within the City of Los Angeles occur principally along and adjacent to the high palisades, or sea cliffs, bordering the northwestern part of the Los Angeles coastal plain. The palisades, now protected from wave erosion by beaches and fill embankments, extend along Santa Monica Bay for about 6 miles and reach a maximum height of 300 feet. Locally they are vertical or overhanging. The cliffs are breached by a series of deep narrow canyons leading to the sea from the Santa Monica Mountains.

In their eastern half, the palisades expose nearly flat-lying Pleistocene gravels and sands, predominantly alluvial in origin. The characteristic slope failure is soilfall, which has resulted in essentially parallel slope retreat.

To the west, the palisades expose folded, jointed, and faulted sedimentary rock of Cretaceous and Tertiary age with only a thin capping of the Pleistocene gravels and sands. The highly permeable Pleistocene sediments conduct underground water into structurally weak bedrock. Slope failures have been frequent and extensive, with slumps and bedding-plane slides common. The most troublesome rock is strongly jointed clay shale of late Miocene age, which locally dips seaward in the cliffs.

The landslides of the palisades have had disastrous economic consequences for many property owners and have created serious and costly problems for utility companies and municipal agencies. Safety of travelers on the major highway at the base of the palisades has been repeatedly jeopardized.

SEDIMENTARY AND DEFORMATIONAL STRUCTURES IN GLACIER ICE—A PROGRESS REPORT

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Glacier ice accumulates as a sedimentary deposit which is subsequently metamorphosed by pressure and flowage. This causes the superimposition of many types of deformational structures on a primary stratification. Observational data on the geometry of stress and deformation rate aid in the understanding of the tectonic structures, and some of these results can be applied to theories of the mode of origin of similar deformational structures in igneous and metamorphic rocks.

Field studies on a cirque glacier in Wyoming, a valley glacier in Alberta, and near the margin of the Greenland ice sheet led to the recognition of three major classes of features: (1) primary stratification, (2) foliation caused by flow, and (3) secondary cracks and crevasses. Stratification and foliation are very similar in appearance, but criteria were developed which allowed about 50 per cent of these structures to be distinguished unequivocally. The foliation was generally parallel to the velocity vector in strike and locally displaced or warped other structures.

The orientation of the surface structures was compared to the orientation of the strain-rate tensor in the surface ice. These studies indicated that at least some foliation attitudes did not relate to measured directions of maximum-shearing-strain rate at the point of observation or at any conceivable point of origin. Two sets of cracks were parallel to the two directions of maximum-shearing-strain rate, and four other sets were almost perpendicular to the directions of maximum elongation and compression rates.

PRECAMBRIAN TILLITIC SCHISTS IN THE SOUTHERN DEEP CREEK RANGE, WESTERN UTAH, AND PRECAMBRIAN UNITS OF WESTERN UTAH AND EASTERN NEVADA*

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Near Trout Creek, on the eastern slope of the Deep Creek Range, a Precambrian metamorphic sequence comprises:

	Feet
Massive quartzite, forming sheared-off syncline	1500+
Schists with quartzitic layers	3000+
Tillitic biotite schists	1000±
Biotite-muscovite schists	300±
Quartzites and quartzitic schists	600±
Biotite-muscovite schists and minor hornblende schists; including 300–400 feet of tillitic schist in two members	1000±
Base not exposed	

The regional metamorphism is mesozonal, with biotite, garnet, hornblende, and epidote. Schistosity parallels bedding. Migmatites are lacking.

The tillitic rocks are fine-grained quartz-biotite schists containing angular to subrounded partly drawn out fragments, up to 1 foot across, of granites, gneisses, migmatites, schists, schistose quartzites, and marbles, derived from older metamorphic rocks. Bedding and sedimentary lamination are preserved. Deposition was by iceberg rafting.

The older metamorphic unit, the source of the tillitic material, is exposed in the northern Snake Range and the northern Ruby Mountains. It includes migmatites, gneisses, schists, schistose quartzites, amphibolites, and calc-silicate marbles. Rocks believed contemporaneous with the metamorphic unit to which the tillites belong occur in the Schell Creek Range and elsewhere. A younger Precambrian unit, including quartzites, slates, and argillites, is exposed in the southern end of the Deep Creek Range, in the Snake Range, and in the Schell Creek Range.

These three Precambrian units constitute the lower plate of a regional *décollement* (Snake Range thrust). Mylonitization at the thrust has produced retrogression in the Precambrian metamorphic rocks and localized low-grade dynamic metamorphism in the Paleozoic rocks. Thus Precambrian age of the regional metamorphism is confirmed.

PLANE-WAVE REFLECTION AND TRANSMISSION COEFFICIENTS AT AN INTERFACE OF LARGE VELOCITY CONTRAST

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Displacement potentials for transmitted and reflected compressional and shear waves are given in an explicit form particularly useful for numerical computation of both amplitude and phase. These equations are used to calculate the fractional energy in the reflected, transmitted, and transformed waves arising from plane P or S waves incident on either side of a plane interface separating two solid media of large velocity contrast. The cases computed are $\alpha/\alpha' = 2/5$, $2/6$, and $2/7$, where α and α' are the velocities for compressional waves above and below the interface. In the computation Poisson's ratio in each medium was taken to be 0.25. The explicit equations for the amplitudes are not restricted to the case of large velocity contrast or to any particular choice of values for the Poisson's ratios. The results are used to discuss certain problems arising in deep-sea seismic-refraction work.

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WAUCOBAN STRATIGRAPHY, INYO MOUNTAINS, CALIFORNIA

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More than 12,000 feet of well-exposed Lower Cambrian strata occurs extensively in the Waucoba Mountain and Blanco Mountain quadrangles, Inyo Mountains. Structural complications are considerable, but the stratigraphic succession is clear and can be related directly to the poorly exposed, faulted composite section described by Walcott at Waucoba Springs, several miles to the southeast. The Inyo Mountain succession comprises a revised type Waucoban Series. Similar, but less certain, comparisons can be made with Walcott's section at Barrel Springs, south of Silver Peak, Nevada. Field examination of the Waucoba Springs and Barrel Springs sections indicates that each is incomplete at its base and in part thickened by faulting.

The Lower Cambrian of this region is the Silver Peak Group and in the Inyo Mountains can be divided into seven formations consisting primarily of shale and quartzitic sandstone with lesser amounts of massive to well-bedded limestone and dolomite. Striking lenticularity of both quartzitic and carbonate units is a major feature. Moderate to strong metamorphism, related mainly to plutonic activity, is locally common.

Olenellid faunas are now known to occur sporadically throughout the succession to within approximately 200 feet of the gradational contact with the underlying unfossiliferous Campito sandstone. The Silver Peak strata are conformably overlain by a limestone-shale succession bearing the Middle Cambrian trilobite *Ogygopsis* at its base.

DAMAGING EARTHQUAKE AND BLAST VIBRATIONS

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In the author's booklet, *Earthquake intensity and related ground motion* (University of Washington Press, 1954), .064 g is cited as a ground acceleration corresponding to MM Intensity VI earthquake motion in the central area of an earthquake. This is the lowest grade that stipulates potential cracking and falling of plaster in small amount.

In 1942 the U. S. Bureau of Mines issued Bulletin 442, *Seismic effects of quarry blasting*, which cites accelerations from 0.10 to 1.0 g as a "Caution" zone in which ground vibrations "approach dangerous proportions"; 1.0 g and over indicate "imminence of damage" but "may not produce damage".

The apparent disagreement between these two findings can be reconciled if, for one thing, one accepts without reservation the Bureau of Mines' experimental results showing that plaster can crack when a building acceleration is approximately .10 g, and plaster can fall when it is approximately .30 g. Such building accelerations can be deduced from the author's Intensity VI ground accelerations (ranging from approximately .04 to .10 g) if the latter are increased 3 or 4 times to take care of the possibility of experimentally observed resonance and related phenomena which tend to amplify the motion of a building shaken by ground vibrations.

ORIGIN OF THE ALGODONES DUNES, IMPERIAL COUNTY, CALIFORNIA

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The Algodones Dunes or Sand Hills, extending 45 miles along the eastern side of the Imperial Valley, California, comprise one of the largest dune tracts in the United States.

Evidence indicates that most of the Algodones dune sand was derived from beaches along the shore of ancient Lake Cahuilla which occupied the Salton Basin during Late Pleistocene and early

Recent time. The beach sand is believed to have been transported southward along the eastern shore of the lake from the mouths of the Whitewater River, Salton Creek, and Mammoth Wash by persistent long-shore currents generated by vigorous winds entering the basin chiefly from San Gorgonio Pass to the northwest.

Present distribution of the dunes suggests that the Late Pleistocene winds blew nearly parallel to the eastern shore of the lake as far south as Mammoth Wash, where, owing to a southward bend in the shore line, the winds blew inshore and carried much beach sand with them. Inshore transport of sand north of Mammoth Wash was considerably restricted by the foothills of the Chocolate Mountains.

Dune configuration, sand color, grain size, and roundness all suggest that beach sand has migrated from north to south and that the southernmost dunes are somewhat older than those farther north.

PRECAMBRIAN GRANULITE IN THE WESTERN SAN GABRIEL MOUNTAINS, CALIFORNIA

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A dark gneiss of unusual appearance and characteristics crops out over an area of 9 square miles in a belt 10 miles long just north of the San Gabriel fault. The gneiss, comprising bluish quartzo-feldspathic granulite, greenish-brown amphibolite, biotite schist, and intrusive metadiorite is well exposed and characteristically developed on the ridge topped by Mendenhall Peak, elevation 4582. The predominant rock type, quartzo-feldspathic granulite, consists of 16–40 per cent late anhedral blue quartz, 20–65 per cent antiperthitic plagioclase, a small percentage of late anhedral microcline, relict hypersthene largely replaced by aggregates of green hornblende, biotite, quartz, chlorite, and calcite, and minor ilmenite, pyrite, and garnet. Texture is fine to coarse xenoblastic granular. Two chemical analyses show 69.50 and 74.82 per cent silica, respectively. These analyses, computed norms, and modes of 12 specimens are strikingly similar to the acid to intermediate charnockites in other parts of the world described by Pichamuthu (1953).

The general trend of highly irregular gneissic banding, or foliation, is west-northwest, parallel to structural trends in the San Gabriel fault zone. The most frequent dips are steeply south, off the anorthosite-gabbro core of the range.

The granulite has been intruded by rocks of the Precambrian anorthosite-gabbro group, including sill-like bodies of anorthosite parallel to gneissic foliation, crosscutting olivine gabbro, and dark altered noritic rocks (age 930 ± 90 million years: Neuerburg and Gottfried, 1954) which cut across the granulite in Pacoima Canyon and carry numbers of inclusions of blue-quartz gneiss. This granulite and intruding anorthosite group constitute the only dated Precambrian rocks southwest of the San Andreas fault.

HIGHER MODES OF CONTINENTAL RAYLEIGH WAVES

Jack Oliver and Maurice Ewing
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A long dispersive train of waves corresponding to higher modes of the Rayleigh wave equation (including Sezawa's M_2 wave) for the continental crust-mantle system is positively identified, apparently for the first time. Observed particle motion is elliptical and retrograde, in agreement with theory. Although several theoretical studies have been published in which progressive elliptical-particle motion was found, all of them involved values of the elastic constants unsuitable for the present problem.

The beginnings of the short-period branches of the higher modes can account for the high-frequency longitudinal and vertical components of the continental surface-wave phase L_g. The large amplitudes and the peculiar appearance of R_g appear to depend on the broad flat minimum of the group-velocity curve of the lowest or Rayleigh mode.

SEA-LEVEL CHANGES ON SANTA ROSA ISLAND, CALIFORNIA

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Santa Rosa Island, one of the Santa Barbara Channel group in southern California, offers a unique opportunity to study Pleistocene sea levels by the several subaerial and submarine terraces that indicate nearly 800 feet vertical differentiation in about 13 miles of cross section. Time elements are indicated by several radiocarbon dates, fossil bones, and archeological material for the Wisconsin and Recent periods. Excavation, laboratory analysis, and soundings have been carried out by the Santa Barbara Museum of Natural History—"Santa Rosa Island Expeditions"—since 1946, with the active co-operation of Lamont Geological Observatory, Columbia University; Allan Hancock Foundation, University of Southern California; the Western Speleological Institute Inc.; and others.

Terraces, or wave-cut platforms, with their alluvial covering containing fossils of the dwarf mammoth, indicate an Illinoian age for the 300-foot terrace, a Wisconsin age for the lower alluvial terrace, and a Third Interglacial age for the 25-foot wave-cut platform. A submarine survey extending the previously known section, made with the co-operation of K. O. Emery, shows four terraces, whose ages are uncertain.

The radiocarbon dates suggest that the sedimentation of Wisconsin beds on Santa Rosa Island was completed about the time (11,000–12,000 years B.P.) when Lake Lahontan reached its maximum, and very good agreement is found with the sharp climatic change recorded by Lamont in the Atlantic Ocean cores.

ANNUAL GROWTH ZONES IN BONE OF LOWER PERMIAN VERTEBRATES

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A fossil fauna of amphibians and reptiles from Lower Permian fissure deposits (Arroyo correlative) of Fort Sill, Oklahoma, possesses conspicuous and regular growth zones in certain bones of the skeleton. At present, zones have been found in a cotylosaur (*Captorhinus*), a pelycosaur, two microsaur amphibians (*Euryodus*, *Cardiocephalus*), and in a labyrinthodont amphibian, all of small size. Zones appear most clearly in thin sections of the dentary bone; surface expression of zones is present but rare.

Close similarity of the fossil zones to annual growth zones in Recent poikilotherms (fish and tetrapod) living in environments characterized by alternating dry-wet tropical or hot-cold temperate climate indicates that the growth zones of the Permian fauna are annual. It is concluded that these zones afford clear evidence of seasonal cycles in the Early Permian environment of the fauna. This conclusion signifies a new approach to paleoclimatology.

Correlated study (in progress) of the associated deposits may help to determine if the seasonal cycles indicated by the fauna represent cycles in a tropical or temperate climate. Discovery of annual zones in fossil poikilotherms suggests lines of study in paleophysiology—*e.g.*, patterns of growth, and age and longevity of individuals; presence or absence of poikilothermy in therapsid reptiles.

MARINE PLIOCENE FAUNA IN NORTHWESTERN SONOMA COUNTY, CALIFORNIA

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A collection of fossils made by Charles Higgins from the area between the Russian River on the south and Gualala on the north, and east of the San Andreas fault indicates the presence of a large

area of late Tertiary marine sediments. The fauna consists of about 43 species including *Anadara trilineata*, *Arca* n. sp., *Clinocardium meekanium*, *Patinopecten purisimaensis*, *Chlamys egregius*, *Schizothaerus pajaroensis*, *Schizopyga moraniana*, *Colus recurvus*, and *Terebratalia arnoldi etchegoini*. This assemblage is indicative of the Pliocene and is tentatively interpreted to indicate an age equivalent to that of the lowermost Merced formation of the San Francisco Peninsula or the upper Purisima formation of the Santa Cruz quadrangle. The fauna suggests that during the time of deposition the temperature was somewhat warmer than at the present.

Fe^{++} AND Fe^{+++} RATIOS IN SATURATED AND UNSATURATED SANDSTONE, OLJETO SYNCLINE, NAVAJO COUNTY, ARIZONA

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Drill core from diamond-drill holes in the Oljeto syncline, Monument Valley, Arizona, have been analyzed for Fe^{++} and Fe^{+++}, and these data have been related to rock color and the regional water table. Sandstone from the Shinarump member of the Chinle Formation of Triassic age that is shades of gray, green, and blue comes from below the regional water table where the rocks are saturated. Sandstone locally gray but with predominant shades of brown and yellow is from the zone of aeration in areas where the rocks are occasionally charged by percolating water. On outcrop this same sequence of rocks is shades of yellow and brown except near the base of channels in the underlying Moenkopi Formation where it is gray.

The ratios of ferrous to ferric iron in these permeable sediments and the relation of these ratios to the position of the water table suggest that a large part of the brown and yellow hues are produced by oxidation accompanying unwatering of sediments during late Tertiary or Quaternary time.

MODEL STUDY OF ELASTIC-WAVE RADIATION FROM FAULTS

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An approximate ultrasonic representation of an impulsive strike-slip fault is used to study the radiation of compressional and shear waves. Variations of amplitude, direction of motion, and spectrum of the elastic wave pulses with azimuth are described. The behavior of the compressional wave follows geometric theory. Diffraction effects caused by the finite length of the fault are pronounced for the shear waves, producing significant motion where nodes are expected on the geometric theory. The relation of this work to current practices in obtaining fault-plane solutions is discussed.

NEW RESULTS FROM LONG-PERIOD SEISMOGRAPHS

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The following long-period instruments have been in operation at the Seismological Laboratory for almost a year: (1) a Benioff vertical reluctance seismometer, $To = 2$ sec., $Ro = 130{,}000$ ohms, capacitor shunt 100 mfds, $Tg = 180$ sec., $RDX = 130{,}000$ ohms; (2) Press-Ewing vertical and east-west seismographs, $To = 30$ sec., $Tg = 90$ sec. For wave periods greater than several minutes the responses are approximately the same, whereas for waves shorter than 30 sec. the response of the Benioff instrument falls off more rapidly because of the capacitor. Using both types of instruments the following results have been achieved: (1) mantle Rayleigh waves and *G* waves are recorded frequently from earthquakes with magnitudes as small as 6½–7; (2) the gap in the dispersion curve connecting crustal and mantle Rayleigh waves has been filled; (3) relatively long-period body wave

pulses ($T > 30$ sec.) are clearly observed owing to the reduced response to the shorter-period, continuing earthquake motion; (4) the impulsive initiation of the Rayleigh waves corresponding to the components of maximum-group velocity is now frequently observed with a characteristic appearance which serves to identify the wave group at sight.

COLLAPSE STRUCTURES IN SPANISH VALLEY, SAN JUAN AND GRAND COUNTIES, UTAH

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U. S. Geological Survey, Grand Junction, Colo.

More than 75 peculiar small collapse structures are strung out along the northeast side of Spanish Valley near Moab, Utah. These structures occur in a belt, about half a mile wide and at least 10 miles long, that parallels the major northwest-trending folds and faults. The collapse structures are nearly oval in plan. Diameters range from less than 100 feet to about 1500 feet. Displacements downward within them are greater than the width of the structures and range from a few hundred feet to 1500 feet or more. The displaced part is commonly brecciated, but slickensides are absent; in some structures the sandstones have been decemented and have flowed steeply inward as shown by foliation. The boundaries of the collapse structures are sharp. The rock outside them generally shows no alteration other than the intrusion of small sandstone dikes and veinlets. Spanish Valley marks the structurally complex central part of the Moab salt anticline, and the collapse structures are probably related to solution at depth of underlying salt and carbonate rocks. The collapse structures are of Tertiary age; they involve Upper Cretaceous rocks and are overlain by lower Pleistocene gravels. The structures seem to be favorable sites for mineralization, somewhat similar to the uraniferous collapse structure at Temple Mountain, San Rafael Swell, Utah. However, none of the collapse structures of Spanish Valley are known to be mineralized.

HYPOTHESIS REGARDING THE ORIGIN OF THINOLITE TUFA AT PYRAMID LAKE, NEVADA*

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Several forms of calcium-carbonate tufa are exposed in the desert basins of Nevada that were formerly occupied by Lake Lahontan. One of these forms is the so-called thinolite, which consists of delicate elongate skeletal crystals, most of which are terminated at both ends by pyramids. The skeletal crystals are made up of many small calcite crystals. Ever since thinolite was first described, its mode of origin has been a subject for conjecture. Thinolite has been studied by Clarence King (1878), E. S. Dana (1884), I. C. Russell (1885), and J. C. Jones (1925), who suggested that the thinolite crystals are pseudomorphs after a mineral chemically precipitated from the waters of the lake. The antecedent mineral is unknown, although gaylussite and aragonite have been suggested. Recent lowering of the water level of Pyramid Lake has exposed thinolite deposits not previously described. On the basis of features thus recently exposed, this paper advances the hypothesis that the thinolite formed in calcareous muds deposited in Lake Lahontan, possibly in association with springs. Features that indicate such an origin are: thinolite found in muds inside tufa domes, some of which may have formed by spring deposits; numerous isolated crystals of thinolite as much as 12 inches long, standing in calcareous shoreline mud and oriented perpendicular to the slanting surface of the mud; increasing delicacy and more skeletal appearance of crystals with increasing depth in mud; and grading of crystals into mud at their bases.

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* Publication authorized by the Director, U. S. Geological Survey

QUARTZ CONTENT OF PELAGIC SEDIMENTS OF THE NORTH PACIFIC OCEAN

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The concentration of quartz in pelagic sediments of the North Pacific Ocean has been determined by quantitative X-ray-diffraction techniques. Values in the clays range from <1 to 20 per cent.

The geographic and topographic distribution of the quartz particles coupled with their size distribution and isotopic composition point to an eolian origin in all but a few areas where either ice rafting or turbidity currents are considered important. On an ocean-wide basis, water transport of the quartz particles appears negligible in the light of present-day knowledge of ocean currents and settling times. The quartz particles, which are found as chips and shards, are well sorted with maximum concentration in the 4- to 16-microns size. Similar size ranges are observed in atmospheric dusts. The highest quartz values are found far from land in deposits containing little or no volcanic contributions and relatively free from dilution by biogenous components. Inasmuch as quartz is only one of the major mineral components of atmospheric dusts, such results indicate that a major fraction of these pelagic clays is eolian.

The quartz concentration in all cores penetrating Tertiary strata is greater in the Quaternary than in the Tertiary deposits. This suggests either an increased rate of accumulation of quartz or a decreased deposition of diluting materials during Quaternary. If the former is the case, this effect may be related to major meteorological differences between these epochs.

GEOLOGY OF THE ISLAS REVILLAGIGEDO, MEXICO

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The Islas Revillagigedo consist from west to east of Isla Clarión, Isla Roca Partida, Isla Socorro, and Isla San Benedicto. The archipelago is about 200 nautical miles south of Baja California and 300 miles west of Mexico. Clarión and possibly Roca Partida appear to be genetically related to the Clarión fracture zone. San Benedicto and Socorro are probably younger and are located on a north-south fissure that lies normal to the Clarión fracture zone. All the islands are composed of lava and pyroclastic deposits of the olivine basalt-trachyte association. Soda rhyolite, the most silicic differentiate found, occurs on San Benedicto.

The principal volcanic peaks on Clarión do not appear to show a preferred alignment. An annular depression or moat partly circles the island at a depth of 2000 fathoms. Roca Partida is the top of an eroded trachydolerite volcanic neck. Socorro, the largest island of the group, is essentially a single, slightly dissected, approximately conical volcano about 3600 feet high with adventive cinder cones and viscous lava flows at its base. San Benedicto is located at the intersection of four submarine ridges, with the major one to the north. Volcán Bárcena, born in August 1952, erupted nearly 10^{10} cubic feet of trachytic ash and lava before it became inactive in March 1953. Glowing avalanches were erupted during cone formation. An index of explosiveness of about 90 per cent is the highest of any known oceanic volcano in the eastern Pacific.

P AND S AT SHORT DISTANCES; PROGRESS REPORT

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Investigation is being carried forward for shocks of magnitude 3 and above, in Southern California beginning in 1954, favorably placed with respect to stations at short distances. Most of them are in Kern County, but there are enough others to sample the general area. About 60 have now been worked out.

Origin times are computed from the arrivals of *P*, assuming velocity 6.34 km/sec. and depth 16 km.; the epicenter is adjusted to make these consistent. For some shocks this is possible for all the nearer stations. For others, times at the nearest stations appear as much as 1 second early relative to those at greater distance; the discordance cannot be removed by shifting the epicenter or decreasing the assumed depth. *S-P* intervals then usually agree best with the earlier origin time, suggesting that arrivals at the more distant stations are delayed. At King Ranch, west of the San Joaquin Valley, arrivals of *P* for shocks in the Kern River region are systematically delayed.

VERTICAL OR PRIMARY WATER

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Hydrology and related Water Engineering have, in about 50 years, transformed a United States which was water and land rich into a land desperately water poor, plagued with dust bowls, drought, and tornadoes and the consequent loss of millions of tons of topsoil per year.

There has been little advance in constructive and scientific thinking regarding the concept of water in that time: What is it? Where does it come from?

The practice to date of water production and transportation, which is mostly of the lateral type, has brought depletion and in some instances denudation and chaos to the places of origin, and has destroyed Nature's cycling process of evaporation and precipitation. A vertical production is needed, with a return to natural laws if we wish to solve the problems of the future.

MIDDLE CRETACEOUS STRATIGRAPHIC UNITS IN THE NORTHWESTERN SACRAMENTO VALLEY, CALIFORNIA

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Two new formations occur in a thick homoclinal section of Middle Cretaceous marine rocks in the northeast quarter of the Ono quadrangle, California. One, a 1000- to 2000-foot conglomerate-sandstone-mudstone unit, is typically developed along Crow Creek (sec. 25, T. 30 N., R. 7 W.; sec. 31, T. 30 N., R. 6 W.). It is conformable with the underlying mudstones that make up the Ono Formation (Murphy, 1956). The overlying 3900-foot formation, a thick mudstone unit with nodular limestones and a prominent sandstone in the upper part, has its type area farther down Crow Creek (secs. 31, 32, 33, T. 30 N., R. 6 W.) directly west of Gas Point. It is unconformably overlain by the Late Cenozoic nonmarine Tehama and Red Bluff formations.

Several foraminiferal zones, probably ranging from late Albian to Turonian in age, are within this section. The *Pervinquieria hulenana* zone (Murphy, 1956) of the underlying Ono formation ranges up into the lower part of the conglomerate-sandstone-mudstone unit.

COMBINED STRAIN-DISPLACEMENT SEISMOGRAPH

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A seismograph system is proposed which makes use of the combined outputs of a strain and a displacement detector. Theoretically, the combined system has a greater capability than either instrument alone for detecting longitudinal waves at near-vertical incidence in the presence of noise caused by surface waves.

AGE OF THE CALIENTE FORMATION, CALIENTE RANGE, CALIFORNIA*

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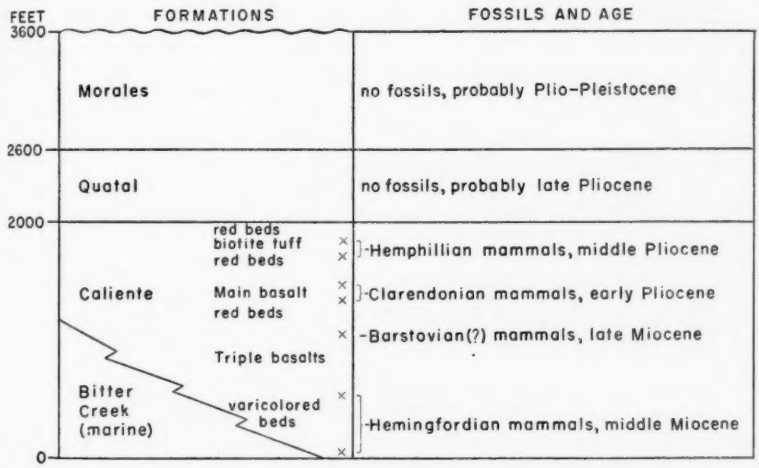
The Caliente Formation, consisting of red and varicolored nonmarine mudstones, sandstones, and conglomerates, is exposed in the Caliente Range and in the Cuyama Valley district. It has been assigned to the middle Miocene, although some workers have suggested a possible early Miocene age for the lower part of the formation in certain outcrops.

New discoveries of fossil land mammals throughout the 2000-foot thickness of the formation in the Caliente Range represent superposed mammalian faunas of four geochronologic ages. A time span from Hemingfordian (middle Miocene) to Hemphillian (middle Pliocene), inclusive, is indicated. The middle Pliocene age assignment for upper beds in the formation is based on the occurrence of advanced pliohippine horses and a megalonychine ground sloth.

Refined age assignment for the Caliente and overlying formations and the approximate stratigraphic positions of the land mammal assemblages are demonstrated on the accompanying chart.

LATER CENOZOIC NONMARINE FORMATIONS OF THE CALIENTE RANGE



STRUCTURES WITHIN THE MALASPINA GLACIER, ALASKA

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Malaspina Glacier is a piedmont ice sheet covering 1000 square miles on the flat coastal foreland of southern Alaska. The broad geometry and structure are simple, but details are complex. An extensive system of radial crevasses, a prevailing foliation, and two sets of tight joints are related to the broad lobate form of the sheet and to compressive and extensive stresses developed therein during the process of spreading out. Dip of the foliation is mostly too steep (75°–85°) to be the product of surfaceward movement and is attributed to squeezing and lateral flow to the sides. An extensive and complex system of folds, spectacularly displayed on the glacier's surface, deforms ice streams and debris bands about near-vertical axes. These structures developed within the Malaspina and are not inherited from higher in the system. The folds are primarily the product of

* Presented with the permission of Western Gulf Oil Company

flowage with minor modification by near-surface slippage, and they formed in response to the strong shove of ice pouring out of the mountains. The Malaspina Glacier accomplishes the complex task of spreading out and at the same time of maintaining sufficient thickness and surface slope to flow uphill by folding accordion fashion.

PRIMARY STRUCTURES OF MAAR RIMS AND THEIR BEARING ON THE ORIGIN OF KILBOURNE HOLE AND ZUNI SALT LAKE, NEW MEXICO

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Modern maars of south-central Mexico are partially to completely surrounded by low rims of stratified pyroclastic debris derived from explosive activity within the throats of the volcanoes. The bedding and upper surface of the pyroclastic deposits dip gently, up to a few degrees, away from the maars on the exterior slopes of the maar rims and steeply, generally near the angle of repose, toward the maars on the interior slopes. Sedimentary structures found near the crests of the maar rims include well-developed cross-bedding and small-scale flow or slump marks. The cross-bedding superficially resembles that formed in a fluvial environment, but near the crests of the maar rims the cross-bedding must have been formed by combined volcanic fallout and eolian erosion and reworking of ash and cinders. Large volcanic bombs, up to 8 or 10 feet across, are scattered through the deposits, and the beds beneath the bombs are invariably severely deformed.

The majority of features of Mexican maar rims are duplicated in rims of pyroclastic debris surrounding Kilbourne Hole and Zuni Salt Lake, New Mexico. Though some of these features have previously been interpreted as indicating a fluvial origin for cross-bedded parts of the deposits of the rim in the case of Kilbourne Hole, it is believed that the cross-bedded parts can be satisfactorily explained only as formed by fallout and reworking of explosion ejecta derived from a vent or vents underlying the present crater.

CONTRIBUTION TO THE STUDY OF ASSOCIATED GEOLOGICAL-ARCHEOLOGICAL RECORDS IN THE WESTERN DESERTS

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Our knowledge of North American prehistory is consistently being extended further into the Pleistocene and is becoming more dependent upon geological, climatological, and paleontological evidence.

From Wyoming to Baja California, from the Channel Islands to Texas the story of Western Pleistocene archeology is being learned from long-abandoned lake and ocean shore lines, playa deposits, and river terraces.

Currently, in the western deserts, three important geo-archeological localities are being investigated by the Southwest Museum: (1) the terraces and associated lake clays of Pleistocene Owens Lake's north shore; (2) terraces of Coyote Lake, San Bernardino County; (3) river-and-pond-deposited clays of the Vegas Wash northwest of Las Vegas, Nevada.

The Owens Lake locality features a series of dunes and blow-outs. On the dunes are found Pinto Basin-type artifacts, probably 3000 or 4000 years old. In blow-outs, cutting into lake clays, is a crude, probably older, lithic artifact assemblage.

The Coyote Lake terrace sequence yields a series of lithic assemblages: Paiute at the Playa edge; Pinto Basin-Lake Mohave on intermediate terraces; crude generalized core tools on the highest terraces.

The Tule Springs locality in the Vegas Wash, Nevada, yields charcoal deposits—old cooking fires—containing bones of Pleistocene horse, camel, bison, and mammoth. One charcoal pocket also yielded a small convex-edged scraper. The charcoal has been dated as older than 23,800 years.

X-RAY STUDY OF ERIONITE, A FIBROUS ZEOLITE

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Erionite was first named and described by A. S. Eakle in 1898. The original material, which came from near Durkee, Oregon, was woolly in appearance and associated with fire opal. This information aided the writer in rediscovering the locality in 1953.

The optical properties of erionite indicate it is orthorhombic, and all x-ray patterns may be indexed on an orthorhombic lattice of the dimensions: $a_0 = 6.625$ Å, $b_0 = 11.53$ Å, $c_0 = 15.12$ Å. The indices of refraction are $n_x = 1.468$, $n_y = 1.470$, $n_z = 1.473$, which are higher than values previously published. Use of Nessler's reagent confirms the presence of ammonia, and the cell content calculation gives a general formula of K Na (Ca, Mg) $Al_4Si_{12}O_{32} \cdot 12H_2O$.

EVIDENCE OF *ALBERTELLA* FAUNA IN SOUTHERN CALIFORNIA

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The only reference to date on the presence of *Albertella* fauna in the Southwest was based on an undescribed pygidium reported by J. F. Mason (1938) from the Highland Range, Utah, and a pygidium from the Grand Canyon described by Resser (1942). During current restudy of Walcott's Lower Cambrian sections in the Inyo Mountains, Professor C. A. Nelson and Mr. R. B. Saul made important finds in the Middle Cambrian part of the sequence which indicate communication with depositional regions of both the Canadian Rockies and Sonora. The *Albertella* zone in the Inyo Mountains is characterized by *Albertella* sp., the pygidium of which differs from that of the Canadian *A. stenorhachis* Rasetti (1951) in having anchylosed spines, parallel to the axis and given off close to the anterior border; in the recently described species of Canada, Arizona, and Sonora (Lochman, 1952) the anchylosed spines tend to diverge in the posterior part of the pygidium. The zonal interpretation is further corroborated by the occurrence of the strata with *Ogygopsis spinulosa* Rasetti (1951) in the same sequence. Noteworthy also is the presence of *Sonoraspis* in close association with the *Albertella* zone. Described first from Sonora (Stoyanow, 1952), and later traced to the Marble Mountains northeast of Los Angeles (Stoyanow and Susuki, 1955), its presence and zonal position in the Inyo Mountains are significant both stratigraphically and paleogeographically.

DIRECTION OF FAULTING FROM FIRST MOTION STUDIES

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The effect of a crustal layer on the surface distribution of initial motion from a crustal earthquake is examined.

For crustal earthquakes a simple modification of the extended distances given by Hodgson and Storey permits the direct comparison of data obtained from a network of near stations with data from distant stations treated by the Byerly method. The patterns of first motion expected at near and distant stations from a given geometry of faulting with different assumed crustal velocities are compared.

In cases where either the fault or auxiliary plane dips at an angle less than about 60° there should be a significant difference in the first-motion pattern. Under certain plausible conditions patterns resembling an explosion or implosion can be obtained.

Previously published first-motion studies are discussed in the light of the above analysis, and in certain cases a modification of the interpretation is necessary.

SEISMOLOGICAL STUDIES OF THE WESTERN RIFT VALLEY OF AFRICA

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Intensity, strain release, and first-motion studies of earthquakes along the Western Rift Valley of Africa, using data from the seismograph network of the Institut pour la Recherche Scientifique en Afrique Centrale in the eastern Belgian Congo, during the period from May 1953 to April 1956 are presented.

Regions of activity shifted during the period of observation; an increase in activity west of Lake Albert in July 1956 is especially noticeable. Intensity maps for three earthquakes show an elongation of isointensity regions parallel to the rift.

The rate of strain release in the area increased with the commencement of the Lake Albert shocks, changing from 35×10^8 ergs$^{1/2}$ to 155×10^8 ergs$^{1/2}$ per 100 days. Strain released during several aftershock sequences was proportional to the logarithm of the time after the initial shock.

First motions from Rift Valley earthquakes to the I.R.S.A.C. stations do not give a unique determination of the predominant type of faulting. The data are consistent with dip-slip faulting along steeply dipping faults parallel to known faults in the region with motion such that the elevated areas are being further elevated and the depressed areas further depressed. They are also consistent with strike-slip faulting along near-vertical faults with the eastern sides moving north. In agreement with the near-station results, first-motion data from distant stations for two shocks west of Lake Albert indicate some combination of reverse dip-slip and sinistral strike-slip motion along a fault plane dipping toward the rift valley.

SUBMARINE GEOLOGY OF SANTA MONICA BAY, CALIFORNIA

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The texture of the bottom sediments in Santa Monica Bay shows a gradual progressive change from sand near shore to silt off shore; however, this progression is partly disrupted by areas of relict sediment, authigenic minerals, organic debris, and rocky bottom. Organic carbon and $CaCO_3$ increase in an off-shore direction and are correlated with the submarine topography. Evidence indicates that sedimentation over most of the Bay is extremely slow, and nondepositional areas exist in some parts of the Bay. Marked changes in the depositional history of the Bay are shown by comparison with older sediment studies and extreme textural variations found in cores and borings. Thick deposits of clay and layers of vegetation in the near-shore region are interpreted as being deposited as marsh deposits behind off-shore bars. The landward extension of these off-shore bars may have been the source of the sand in the El Segundo Sand Hills.

Bedrock recovered from the outer shelf and from the submarine canyons is chiefly Miocene age rocks. On the outer shelf, Foraminifera of Lower Mohnian age were identified from a mudstone, and, in this same general area, schist of a questionable age was recovered. The outer shelf where the bedrock occurs is a topographic high and has not been covered by post-Pliocene sediments. This topographic high area is separated from the eastern part of the Bay by a syncline or consists of a monoclinal dip toward the coast. Faulting may be responsible for the present geological structure of the Bay.

CRUSTAL MODELS BASED ON RECENT PRESSURE-TEMPERATURE-VELOCITY MEASUREMENTS

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Recent measurements by D. S. Hughes and C. Maurette of the variation of elastic wave velocities in granites and several basic igneous rocks have been carried to pressures and temperatures corresponding to depths approaching that of the Mohorovičić Discontinuity under continents.

Travel-time curves have been computed for crustal models based on these measurements. One simple distribution of elastic parameters with depth is shown to produce the Zed Phenomenon, even in the absence of extended faulting.

Another simple model has a distribution of velocities with depth such that the lower part of the crust could serve as a channel for the propagation of rotational waves, but not for compressional waves, thus providing a possible explanation for the weakness or absence of π_g in contrast to the great strength of L_g along continental paths.

COALESCENT GROWTH OF PLAGIOCLASE GRAINS IN IGNEOUS ROCKS

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In many igneous rocks euhedral oscillatory zoning in plagioclase records the coalescent growth of small plagioclase grains to tightly knit groups of larger grains. Coalescence begins when euhedral plagioclase crystals have either moved or grown together to form glomeroporphyritic groups. Once the crystals are in contact, mutual interference prevents development of complete zonal shells around the individual grains; instead, the group acts as a unit in receiving successive zones. Such a zone is, in a sense, composite and envelopes the group and passes with abrupt change in direction across grain boundaries, changing its optic and crystallographic orientation to conform with the individual crystals. The boundaries of the individual grains are euhedral, except in contact with other grains in the coalescent group; this reflects free growth against magma contrasted with interference of contiguous grains. Coalescence implies no molecular, crystallographic, or optical change in the plagioclase, once it has crystallized. Each coalescent grain maintains its identity throughout its development.

Coalescent grains may develop as irregular intergrowths and complex penetration forms. Some of these resemble twins but, unlike twins, have irregular boundaries and lack consistent arrangement of their component parts. Some grains which join on 010 before coalescence simulate Carlsbad twins.

Coalescent growth characterizes porphyritic andesites and basalts and many igneous quartz diorites and granodiorites. The contrast between the euhedral zones and outer boundaries of the coalescent grains and their irregular mutual boundaries is thought to be compatible only with crystallization from magma and to be a criterion of igneous origin.

AGE OF THE VASHON GLACIATION IN THE SOUTHERN AND CENTRAL PARTS OF THE PUGET SOUND BASIN, WASHINGTON

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Recent radiocarbon dates and stratigraphic studies suggest that the Vashon glaciation in the southern and central parts of the Puget Sound basin consisted of a single advance and retreat in Wisconsin time.

Three wood samples (W-257, W-258, W-259), from Pleistocene sediments underlying Vashon drift but separated from it by an unconformity, are all older than 37,000 radiocarbon years, indicating that earlier glaciations are of pre-Wisconsin age. Basal peat from a bog on Vashon drift 120 miles north of the terminal moraine of Vashon drift is 12,900 ± 330 radiocarbon years old (W-398). If time is allowed for ice recession of 120 miles and for a lag between ice melting and initial peat deposition, Vashon deglaciation probably began not later than 14,000 years ago.

Precise correlation of the Vashon glaciation with substages of the Wisconsin of the midwestern United States is uncertain. Most Midwest radiocarbon dates imply that the glacial readvance of Cary age began after 14,500 years ago; some dates, however, suggest that the Cary maximum occurred at about this time. Because Vashon deglaciation apparently began in or before early Cary time, and because the glaciation seems to consist of a single advance and retreat, it is suggested

that the maximum of the Vashon is correlative with the maximum of the early Wisconsin glaciation (Farmdale through Tazewell) of the Midwest.

LARAMIDE TECTONIC PATTERN AND IGNEOUS INTRUSIONS IN COLORADO

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Laramide deformation in Colorado was mainly along three regional trends. Major deformation occurred in a broad north-trending belt of folding, faulting, and thrusting, the eastern margin of which is part of an arcuate mountain front extending from central New Mexico to western Montana. Generally milder deformation occurred along a northwesterly zone of uplifts extending from southeastern Colorado to the Uinta Mountains. Still milder deformation, in terms of folding and thrusting, occurred along a less well-defined belt of uplifts extending from the Four Corners region northeastward across Colorado and southeastern Wyoming to the Black Hills. Structures in the Colorado Front Range suggest that this zone was one of wrench faulting, possibly controlled by a northeast-trending regional fabric in the basement complex.

Laramide intrusives were emplaced mainly along the northeast lineament and along the southern part of the frontal zone of deformation. Relatively little igneous activity occurred along the northwest lineament, but the major intrusions in Colorado were localized at the junctions of this zone with the other two.

The sources of volcanic heat, including convection currents, radiogenic heat, and relief of pressure, which commonly are called upon to explain igneous activity in tectonic belts, do not appear to account for the localization of the Colorado intrusives. Recently, speculation has been renewed that volcanic heat is generated, at least in part, by movements along major flaws in the earth's crust and outer mantle. The relationship of Laramide intrusives to zones of thrusting and probable wrench faulting in Colorado appears to support this view.

STRUCTURAL FEATURES OF THE SOUTHERN AMARGOSA VALLEY, CALIFORNIA

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The southern Amargosa Valley area of eastern California lies athwart a major zone of deformation that marks the eastern margin of the great Black Mountain wedge. The rocks of the area are broadly divisible into the following structural units listed in their general order of superposition and decreasing degree of deformation: (1) a generally shattered and disordered basement of Precambrain and Paleozoic metasedimentary rocks, Precambrian diabase, and Mesozoic (?) granitic rock; (2) a much-faulted succession of volcanic and nonmarine sedimentary rocks of probable Middle Tertiary age; (3) moderately folded fanglomerate and lacustrine strata of the Pliocene-Pleistocene (?) China Ranch beds; and (4) similar, but little-deformed strata that were deposited in and marginal to the late Pleistocene Lake Tecopa.

In general, the basement has been broken into imbricate slabs, from a few hundred feet to 2 miles in exposed length, arranged in the form of a northeast-plunging syncline. In several places the slabs have overriden the Middle Tertiary (?) sedimentary units which themselves contain monolithologic breccia layers apparently derived from active fault scarps.

The imbrication seems best attrributed to a zone of crustal shortening beneath the Amargosa Valley. As the imbrication along the western part of the "syncline" has been identified with the Virgin Spring chaos of the Amargosa thrust, at least some of the Amargosa-like thrusting appears to have been rooted in the valley. A continuation of the compression into Pleistocene time is suggested by north-trending folds in the China Ranch beds. These beds also are cut by apparently still later north-trending normal faults.

EUHEDRAL OSCILLATORY ZONING IN IGNEOUS PLAGIOCLASE

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Certain common petrographic characteristics of zoning are not explained by current hypotheses. These characteristics include (1) rhythmic oscillatory zoning combined with (2) a gradual overall increase in albite content toward crystal rims. (3) Individual zones and zonal sequences in the same or adjacent crystals sometimes cannot be correlated.

It is suggested that this oscillatory zoning may result from local reactions between the crystal and the immediately adjacent melt rather than movement of the crystal within the magma or overall physical-chemical change of the magma. Under a low diffusion rate in the melt and at temperatures below the liquidus, a normal zone forms. Its rim approaches the composition of that plagioclase at whose freezing point crystallization occurs. Such crystallization produces a relatively sodic melt adjacent to the crystal and a chemical gradient to magma from which no plagioclase has formed. This chemical gradient steepens until differences in ionic concentrations within the melt cause increased diffusion, tending to re-establish uniformity within the magma, and restoring the melt next to the crystal to nearly its previous composition. Further crystallization without temperature decrease results in a reversal of zoning to a composition nearly as calcic as at the onset of crystallization. The difference between this plagioclase and the earliest plagioclase reflects the gradual removal of anorthite from the cooling magma; thus, successive oscillations become more sodic toward the rim. With continued crystallization, the cycle is repeated as long as the rate of diffusion permits.

After the paper was written, it was found that similar ideas had been expressed by Hills (1936) in Geological Magazine, but these ideas have not been cited in the recent literature.

ABSTRACTS OF PAPERS PRESENTED AT MEETING IN RENO, NEVADA, MARCH 1956
SUPPLEMENTING ABSTRACTS ON PAGES 1761-1787 OF DECEMBER (PT. 2) BULLETIN, 1956

EARTHQUAKES ACCOMPANYING THE 1955 ERUPTION OF KILAUEA

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The 1955 eruption of Kilauea was attended by two remarkable series of earthquakes. The first series originated along the east rift zone of Kilauea where the volcano split open and poured out the lava of the 1955 eruption. These earthquakes appear to have been closely related to the actual splitting open of the fissures that fed the eruption. The second series originated in and around Kilauea caldera in response to the subsidence of the crown of the volcano which accompanied the outpouring of lava along the east rift zone.

Both of these groups were characterized by large numbers of very small earthquakes punctuated at intervals by earthquakes of moderate size. Between February 23 and March 26 about 7500 earthquakes stemmed from the east rift zone eruption area. Between March 6 and April 16 about 11,000 earthquakes, on the average a little smaller than the east rift zone earthquakes, originated in or near Kilauea caldera.

Harmonic tremor of two distinct origins was recorded during the eruption. Rather long period (0.8 to 1.0 sec.) harmonic tremor was generated in the eruption area while lava was being extruded at the surface. From March 7 to March 19 minute, short-period (0.3 to 0.5 sec.) harmonic tremor originated, apparently at a depth of 15 to 30 km, in the vicinity of Kilauea caldera. During the first 5 days of this short-period tremor no lava emerged at the surface.

SEISMOMETRIC RESULTS FROM RECENT HAWAIIAN EARTHQUAKES

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Travel-time studies of some recent Hawaiian earthquakes indicate that the M discontinuity lies as shallow as 15 km below sea level under the island of Hawaii. Velocities of P and S below this discontinuity are about 8.25 km/sec. and 4.75 km/sec. respectively.

Earthquakes of moderate size originate at depths of at least 30 km, well below the M discontinuity. One such earthquake stemming from a focus about 30 km deep and 10 km south of Kilauea caldera on August 14, 1955, awakened people in Honolulu 350 km from the epicenter and was felt on the island of Kauai 500 km from the epicenter; yet it caused no significant damage to structures in the epicentral area.

The deepest earthquakes recorded during the last 2 years have been small. Several swarms of tiny earthquakes accompanying "spasmodic tremor" originated at depths approaching 60 km in the vicinity of Kilauea caldera.

SEISMIC PULSE IN MATERIALS POSSESSING SOLID FRICTION. II: LAMB'S PROBLEM

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Most seismic materials have losses varying as the first power of the frequency; these losses can be described by a pair of related characteristic numbers. One of these is Q, a number similar to the corresponding quantity occurring in electrical-circuit theory. The seismic pulse in such a visco-elastic medium has already been studied for plane waves. The problem has been extended to the propagation of seismic waves through this type of medium under the conditions used by Lamb for the perfectly elastic case. The results show three pulse groups corresponding to P, S, and R events. For high Q, all three pulses are very sharp;

these pulses broaden at rates proportional to the product of the distance and $1/Q$. For symmetric pulse input and high Q, only the R pulse is asymmetric.

Measurements on a seismic model of Lamb's problem in Westerly granite show amplitude dependence consistent only with a Q model of loss. The losses, though small, cannot be neglected. The observed mild changes in R wave form with distance indicate a high value for Q. The changes in wave form can be accounted for by the asymmetric R pulse response and a frequency-modulated input pulse of short duration. From the observed wave-form changes and from the relative amplitudes in the P and R phases, the Q values in both compression and shear are calculated.

SURFACE MOTIONS OF A THICK PLATE

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The motion of a thick elastic slab, infinite in two dimensions and bounded by air on the two parallel faces, has been studied. The slab is excited on one face, as in Lamb's problem, by a point source, impulsive in time, and directed normal to the surface. The early motions of the obverse face are those given by Lamb. The exact solution for the reverse face is obtained in closed form only at the epicenter. The motions at all other points are evaluated by a seismic model. At the epicenter, the measurements and the calculations are in agreement to within 5 per cent; at this point a strong P pulse is observed, and a weaker S pulse is seen. This S phase has a wave form, for short pulses, which is the time integral of the wave form of the P phase. The S phase at distance reproduces the P phase. Off the axis of symmetry, the S phase becomes quite strong, reaching four times the amplitude of the P phase at about 45° in the Solenhofen limestone slab. The large buildup of S is explainable in terms of critical-angle phenomena. A simplified version of the mathematical response for the early phases on the reverse face is constructed. No bodily S-surface P phases are discerned, at angles exceeding the critical angle, having amplitudes greater than the noise level of the system.

MAGNITUDE AND INTERPRETATION OF SOME THRUSTS IN NORTHEAST NEVADA*

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The first description of flat thrusts in the region was in Nolan's classical Gold Hill paper. They lie within one mountain range. Recent reconnaissance farther south and west has revealed some thrusts larger than individual ranges. In the northern Snake Range Hazzard and Misch mapped a shearing-off thrust at which the geosynclinal sediments, greatly shortened by imbricate slicing and folding, have travelled eastward relative to the Precambrian basement, and Easton and Misch found the same shearing-off thrust underlying the Schell Creek Mountains to the west. The minimum extent of the thrust across the strike is 40 miles. A similar fault farther northwest (junction Egan-Cherry Creek Mountains) is possibly the same movement plane. Still farther west, in the northern Ruby Mountains, a shearing-off thrust of the sediments over the Precambrian basement was observed by Hazzard and Misch and is being mapped by Snelson. This thrust closely resembles the one in the Snake Range and is possibly the same movement plane, in which case its east-west extent would be 70 miles. Whether the minimum extent is 40 or 70 miles, the actual displacement is probably considerably less; for along a shearing-off thrust displacement is commonly far less than the extent of the movement plane, in contrast to a "true" thrust of older over younger rocks.

In the Schell Creek Mountains Easton and Misch mapped two higher thrusts. The highest brings older over younger rocks and forms klippes without any root within the range. Both the extent of the thrust and minimum displacement exceed the size of the range.

The peeling-off of the sediments in the eastern part of the geosyncline and their eastward motion relative to the basement require an eastward push exerted by westerly thrust masses—in evidence as higher

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plates in some areas though not everywhere. In terms of active transmission of stress versus more passive yielding, underthrusting from the eastern foreland seems probable. The basal shearing-off plane must break through on the east at some unknown place, possibly in westernmost Utah; that the Wasatch-Nebu thrust front represents its final break-through seems less likely, on account of regional as well as age relationships.

The erosive isolation of remnants of larger thrust sheets in individual ranges indicates that regional flat thrusting is older than Basin and Range structure, the superposed nature of which is confirmed by many other facts.

CRUSTAL MODELS FOR THE SIERRA NEVADA AT THE LATITUDE OF RENO, NEVADA, BASED ON GRAVITY MEASUREMENTS

George A. Thompson
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Gravity measurements made by the Coast and Geodetic Survey and by C. H. Sandberg of the U. S. Geological Survey show a negative Bouguer anomaly reaching −200 mgals and centered a little east of the summit of the Sierra Nevada. Two of the possible solutions for distribution of the mass deficiency or compensation are: (1) a thickened crust above the M discontinuity, as suggested by seismic evidence, or (2) a thickened crust combined with unusually light rocks in the crust. Using Worzel's computed value of 2.84 as the average specific gravity of the crust, and a specific-gravity contrast of 0.4 with the mantle, the first solution requires a crust under the summit area 14 km thicker, and under the basins and ranges east of the Sierra 11.5 km thicker, than beneath an area at sea level. The required root of the Sierra is only 2.5 km relative to the Basin and Range country. In the second solution, 7 km of granitic rocks of the Sierra Nevada batholith (specific gravity about 2.7) replace that much "average crust", and the 2.5-km root is eliminated. Correlation of the gravity anomaly partly with granitic rocks suggests that the granitic rocks reach their maximum thickness 10 to 30 miles east of the summit of the main Sierra block. The most likely explanation for the Cenozoic rise of the Sierra Nevada is perhaps not buoyant elevation by a root formed many millions of years earlier in the Mesozoic orogeny but thermal expansion, with possible phase changes, accompanied by the Cenozoic volcanism.

OBSERVATIONS OF HIGHER-MODE RAYLEIGH WAVES*

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It is well known from theoretical work that higher modes of Rayleigh waves are possible. However, there are few observations of these modes. Some data for higher-mode Rayleigh waves are presented.

Small charges of explosive were fired, and the resulting surface waves were observed with low-frequency vertical geophones and appropriate amplifiers at distances of about 1000 feet. Two distinct trains of surface waves were observed. A limited number of observations with horizontal-component geophones showed the first train to be forward-turning and the second train retrograde-turning ellipses. The near-surface structure consists of approximately 250 feet of semiconsolidated sand overlying limestone. The wave lengths were too short for the limestone to have materially affected the dispersion. Studies of P wave refraction indicate a very low-velocity (850 ft/sec) zone at the surface. At the water table at a depth of 5 to 10 feet the P wave velocity jumps to about 5500 feet/sec. No theoretical dispersion curves based on this sort of structure with matching shear-wave velocities will fit even crudely either of the observed dispersion curves. However, if it is assumed that the shear-wave velocity increases much less rapidly with depth than does the P velocity, and specifically that it increases more or less linearly (exponentially) with depth, the observed dispersion can be explained. The first wave train is then the first mode, and the second wave train is the Rayleigh mode. The forward-turning elliptical motion in the first mode is in accord with the theory.

An attempt is to be made to obtain a shear-wave refraction profile to verify a postulated structure.

* This work was performed under the sponsorship of the Dept. of the Army, U. S. Signal Corps.

ABSTRACTS OF PAPERS PRESENTED AT THE MEETING IN LOGAN, UTAH, MAY 10–11, 1957

ROCKY MOUNTAIN SECTION (GSA)

WHITEHORSE QUARTZ MONZONITE, EASTERN NEVADA

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The Whitehorse stock, at the south end of Whitehorse Mountain in eastern Elko County, Nevada, about 20 miles west of Gold Hill, Utah, covers an area of nearly 8 square miles, is roughly circular, and is in contact on the northern, eastern, and southern margins with intensely folded Devonian and Mississippian beds; the western contact is covered by alluvium. The pluton consists principally of pinkish quartz monzonite of variable texture, but types range from granite to granodiorite. A fine-grained variety has been noted near the west center of the stock, and in some areas dark minerals are so abundant as to warrant notation. Profuse aplitic dikes occur locally, and two small basic dikes cut the quartz monzonite near the northern border. Mineralization, restricted to areas along the contacts, consists of intensive silicification, weak copper and tungsten deposition, and the development of small pods of tactite.

North of the Whitehorse pluton the sedimentary rocks are folded into a north-south trending anticline. East and south these beds appear to deviate and wrap around the quartz monzonite with an outward dip. Along the northern border they are overturned steeply toward the southwest causing the quartz monzonite to be in contact with the upper parts of the beds. The pluton is presumed to have been emplaced after the folding, and its geographic position determined by structural factors.

GENESIS OF THE FOX CLAY, UTAH COUNTY, UTAH

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A field and laboratory study of the Fox clay deposit, Utah County, Utah, was made to determine the spatial distribution and paragenesis of the clay minerals, particularly halloysite, in the deposit.

The clay minerals that constitute the deposit are predominantly montmorillonite with some halloysite and a minor amount of kaolinite. These clay minerals are interbedded with travertine and relatively unaltered lenses of volcanic tuff.

Alteration of the tuff was accomplished by Tertiary (?) hot-spring waters. The resulting montmorillonite developed in the zone of leaching by near-neutral hot-spring water; halloysite and kaolinite developed in pockets in the intensive, more basic leaching zone nearest the center of hot-spring activity.

Experiments were conducted on phase relations in a part of the system lime-alumina-silica-acid-water which approximates the probable chemical environment; the results support the formation of halloysite·$4H_2O$ in this nonequilibrium system.

SEQUENCE OF LATE TERTIARY EVENTS ON THE KOLOB TERRACE, IRON COUNTY, UTAH, AS INTERPRETED BY ELEVATED SURFICIAL DEPOSITS

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The Kolob Terrace in southeastern Iron County, Utah, contains an abandoned, gravel-covered pediment and related abandoned stream-channel deposits at elevations of about 9000 feet, which have not been described. These deposits are related in composition, texture, and origin to younger deposits, 3000 feet lower in elevation at the base of the Hurricane Cliffs. The integrated system of deposits spans a period of time extending from post-Miocene (?) to Quaternary and provides a means of measuring early stages of uplift on the Hurricane fault zone. As interpreted by the deposits, the

first major uplift on the fault, which began in post-Miocene (?) time, exposed only beds of Cretaceous age at the base of the Hurricane Cliffs; the second uplift exposed the Navajo sandstone. The remaining displacement on the fault, which has taken place in Quaternary time, has exposed beds in the lower part of the Moenkopi Formation.

IMAGE PROJECTION BY FIBROUS MINERALS

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Compact and parallel fibrous aggregates, mineral examples of which are ulexite, trona, and halotrichite, exhibit an optical effect which heretofore has been recognized only in synthetic fiber aggregates. The image of an object placed against a surface cut across the fibers is projected along the fibers to the opposite surface by reflections on the fiber interfaces. These interfaces act as reflecting surfaces because of the different indices of refraction that exist across the interfaces. Different indices result from (1) the multiple polysynthetic twinning and (2) the manner of orientation of the light-vibration directions in the fibers.

The image is projected whether (1) the light comes from above only, with the object on an opaque surface and with the sides of the crystal aggregate covered; (2) the light comes only from below through a partly transparent object; or (3) the light is reflected off the surface and to the transverse surface of the tilted section.

The image is the sum total of images produced by each fiber; this results in a ragged edge, since the image edge follows the mosaic-fiber interfaces.

Crystal structure is a factor in producing the optical effect only in the sense of determining fibrous growth in minerals. *Note:* The three major diffractions of ulexite, previously not reported, are 12.3, 7.89, and 6.06 Å.

SEISMIC RESULTS OF QUARRY BLASTS AT LAKESIDE AND PROMONTORY POINT, UTAH

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Tentative seismic results are given for the explosions detonated at Lakeside, Utah, on November 20, 1956, and Promontory Point, Utah, on January 4, 1957. The charge sizes were approximately half a million and a million pounds of explosives, respectively. The vibrations were recorded by earthquake seismographs in the Rocky Mountain region, and arrival times were analyzed to determine the depths to the major crustal layers in the region.

Longitudinal waves with a velocity of about 5.7 km/sec. arrived first to distances as far as 125 km from the explosions. From this distance to at least 800 km from the explosions, longitudinal waves with a velocity of approximately 7.8 km/sec were the first arrivals. Assuming these two velocities as constant and 125 km as the critical distance, the depth to the M discontinuity is about 25 km. The data suggest that there may be at least one velocity discontinuity above the M discontinuity. Arrivals having a velocity of 3.4 km/sec, interpreted as Rayleigh waves, were correlated to distances of 325 km.

PITCHBLENDE OCCURRENCES IN THE GOLDEN GATE CANYON-RALSTON CREEK AREAS OF JEFFERSON COUNTY, COLORADO

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Four mines are producting pitchblende from fissure veins which cut the Precambrian metasediments of the Idaho Springs Formation. Mineralization is localized in veins complementary to the large northwesterly trending brecciated faults that dissect the Colorado Front Range. Uranium

mineralization at the Schwartzwalder Mine, the largest of the four commercial deposits, is localized in the refracted portions of faults which pass through a band of garnetiferous biotite gneiss.

The garnetiferous gneiss layer ranges in thickness from 50 to 150 feet. It marks the contact between a thick section of overlying quartz-rich muscovite schist and a wide zone of underlying lime-silicate and amphibolite gneisses containing local lenses of quartzite. Three of the commercial deposits occur in the garnetiferous biotite gneiss layer. The fourth deposit is in the hornblende-rich amphibolite gneiss. All radioactive anomalies are in these iron-rich rock types. No mineralization has been found in the quartz-rich muscovite schist or the limes silicates and quartzites.

At the Schwartzwalder Mine, the U_3O_8 content drops from several per cent to practically nothing as the veins pass from the garnetiferous biotite gneiss into the overlying schists and underlying quartzites. In addition to favorable structural controls, field evidence suggests the possibility of chemical control by rock types rich in ferrous iron.

DISTRIBUTION AND PETROGENESIS OF THE MOUNT MORRISON GRANITE, FRONT RANGE, COLORADO

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The Mount Morrison Formation is the oldest Precambrian granitic rock of the Front Range. It crops out over the eastern flank from about 12,000 feet altitude on the Continental Divide to 8000 feet at the foothills contact. The formation consists of delicately gneissoid granite, migmatite, injection gneiss, granitized quartzite, aplite, and pegmatite.

The type locality is the granite stock of Mount Morrison, west of Denver. During field work throughout the Range (1954–1956) many plutons of granitic rock designated quartz monzonite gneiss by Ball (1908) and orthogneiss by Lovering and Goddard (1950) were found to be of Mount Morrison age and chiefly metasomatic in origin.

Occurrences include: (1) Falcon Mountain stock, Santa Fe Mountain stock west of Denver, Harris Park south of Mount Evans where the migmatite contains numerous dikes of Boulder Creek granite and Wilson Park at the south end of the Range where dikes of Pikes Peak granite cut the Mount Morrison. (2) Sill-like sheets interlayered with mica schist, quartz gneiss, impure quartzite, and hornblende gneiss between Santa Fe Mountain and Mount Morrison, among the quartzites along Cache la Poudre River, and between Log Cabin and Sherman batholiths.

Mount Morrison gneissoid granite and migmatite grade into bedded impure quartzites of unquestioned sedimentary origin. The boundaries of the plutons and the gneissosity within are essentially parallel to the foliation of enclosing rocks. The granitic rock is literally soaked in pegmatite and aplite. The distinctive lithology indicates metasomatic origin for most of Mount Morrison Formation.

NEW LOOK AT *ELRATHIA KINGII* (TRILOBITA)

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This paper presents the results of a study of 341 complete specimens of the Middle Cambrian trilobite *Elrathia Kingii* (Meek) from the Wheeler Formation, Utah. The following descriptive addenda were noted: (1) the proximal "nodes" on the thoracic segments described by Meek proved to be secondary structures resulting from a fracture along an inherently weak zone parallel to the axis; (2) granulosity is variable within the species; (3) the pygidium has but four axial segments; (4) the number of thoracic segments is 13 but may range within narrow limits.

Almost all the specimens collected have fibrous calcite incrustations on their ventral surfaces. A study of the cone-in-cone structure in the calcite shows that its formation was controlled by the trilobite carapace.

Reconstruction of the Wheeler environment indicates moderately deep (600 feet ±) calm water in a restricted area on the edge of or off the shelf of the miogeosyncline.

The single species is treated statistically. Various relationships were plotted, and the appropriate data computed. The trilobite life-ratio curves were constructed, and the various growth stages defined statistically. The use of simple ratios as a taxonomic and descriptive tool is studied, and evidence indicates they are useful only when considered in the light of total life of the trilobite, plus their variance.

The problem of molting and its effect on frequency distributions is examined. It is concluded molts affect only the kurtosis of the distribution.

The survivorship curve for a trilobite is constructed for the first time and considered a useful tool in population interpretations.

GEOLOGY OF PRECAMBRIAN ROCKS, FRENCH CREEK AREA, ALBANY AND CARBON COUNTIES, WYOMING

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The French Creek area is located on the west slope of the Medicine Bow Mountains, southeastern Wyoming. These mountains are developed on an asymmetric anticline, bounded on the east flank by low-angle thrust faults which place Precambrian rocks on Paleocene conglomerates. Post-Paleocene erosion has exposed a large complex of Precambrian igneous and metamorphic rocks.

A sequence of low-grade metamorphic rocks with a maximum thickness of 24,000 feet was mapped. The sequence consists, from oldest to youngest, of schists, thick quartzite units, argillaceous marble, phyllite, marble, greenstone, and slate. These units form the southeast flank of a Precambrian anticline, the axial surface of which strikes N. 45° E. The foliation of the gneisses and schists forming the core of this anticline is discordant to the anticlinal structure. This relationship suggests that the low-grade metamorphic rocks unconformably overlie the gneisses and schists. The uppermost unit of the low-grade metamorphic sequence dips steeply beneath a gneissic complex, the foliation in which parallels the axis of the Precambrian anticline.

Mafic intrusive bodies are common, and the emplacement of many was controlled by joints and faults. These mafic rocks have been altered to amphibolites. Mineralized quartz veins, containing chalcopyrite, gold, and pyrite, are commonly associated with transverse faults.

A similar sequence of quartzites, marbles, and schists is exposed in the Sierra Madre Mountains, 15 miles west of the French Creek area, and has approximately the same structural trend. The Precambrian structural trend was approximately normal to the trend of the Laramide structure.

STRATIGRAPHIC CORRELATION OF LIGNITIC URANIUM DEPOSITS IN THE SENTINEL BUTTE MEMBER, BILLINGS COUNTY, NORTH DAKOTA

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Uranium deposits are in lignitic beds in the Sentinel Butte Member of the Fort Union Formation of Paleocene age. The determination of stratigraphic relationships of economically important beds, their continuity, position, and structural setting is critical from the standpoint of predictability and discovery of uranium deposits.

Individual units of the Sentinel Butte Member of continental origin are extremely lenticular. Coal beds pinch out, thicken, thin, and split into thinner coals and/or peat-clay or carbonaceous-clay equivalents.

Two biostratigraphic or coal-facies intervals were identified and used for correlation in the Sentinel Butte Member throughout Billings County. The lower coal interval consists of three non-radioactive coals that range in thickness from 2 to 14 feet. The coals are separated by 15 to 60 feet of clays and sands. Three radioactive coal beds constitute the upper coal-facies interval which is about 60 feet above the lower interval. These coals range in thickness from 1 to 4 feet and are separated by 15 to 35 feet of clays and sands.

GIANT GLACIAL GROOVES AND THEIR SIGNIFICANCE IN THE JACKSON HOLE AREA, WYOMING

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Piedmont lobes of pre-Wisconsin (?) Buffalo ice flowed southward and westward into Jackson Hole. Giant grooves cut into bedrock along channelways, as far south as Snake River Canyon, indicate extent of ice and direction of movement. Areal study of grooves and associated features shows:

(1) Ice covered more than 1300 square miles in Jackson Hole and was 2500 feet thick in places.

(2) Some grooves extend beneath the alluvium-covered floor of Jackson Hole, thus indicating little or no erosion in broad valley areas after this glacial stage.

(3) Grooves were cut in hard and soft bedrock ranging in age from Precambrian to Pliocene.

(4) Orientation of grooves is not necessarily related to bedrock structure.

(5) Grooves range in size from minor fluting to U-shaped valleys 400 feet deep and 1500 feet wide.

(6) Longitudinally median points are commonly higher than ends of grooves, indicating they could not be stream channels.

(7) Thin deposits of Buffalo till veneer most grooves; ends of those grooves extending across Flat Creek are buried by a moraine of Bull Lake (?) age.

(8) Difference in elevation between highest and lowest grooves 2 miles apart along the Gros Ventre River is 2000 feet.

(9) Groove swarms occur where principal channelway narrowed, and where ice impinged against moderately sloping valley sides; swarms are not necessarily localized in lee of sources of rock that could have served as abrasive tool.

(10) Most extensive ice sources were Yellowstone Park, Absaroka, and Wind River mountains.

TYPE BRAZER LIMESTONE (MISSISSIPPIAN), CRAWFORD MOUNTAINS, NORTHEAST UTAH

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The Brazer Limestone has been studied in its type area, Brazer Canyon, in the Crawford Mountains of northeastern Utah. A specific type section is designated, and detailed rock descriptions of this and a near-by supplementary section are presented. The Brazer Limestone, in this area, is predominantly a dolomite. Dolomitization is considered to have been a penecontemporaneous or early diagenetic event, not a late secondary feature accompanying the faulting. There are several good, relatively complete sections in the type area. From these, two were chosen to present in this paper. A section in the upper part of Brazer Canyon is considered the type section: another section, 1 mile to the north, documents certain changes in rock type along strike.

The age of the Brazer Limestone is late Mississippian, a fact long known and little refined in this discussion. No beds of definite Pennsylvanian age were found in the type section.

PYROPHYLLITE IN COMMERCIAL CLAYS FROM THE MANNING CANYON FORMATION, UTAH

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Considerable amounts of pyrophyllite have been identified in samples from the brick clay pits bordering the Lake Mountains in Utah County, Utah. Phase-equilibrium studies, as well as known geologic occurrences, show this mineral forms at elevated temperatures in acid to neutral solutions.

The unexpected, localized occurrence of this high-temperature mineral in the beds of the Manning Canyon Formation indicates that hydrothermal alteration has changed the original clay mineral suite in the shale. The altered shale now consists of pyrophyllite, mixed-layer (micamontmorillonite) clay, kaolinite, and quartz. Locally, sericite veins cut the altered shale.

An obvious association of pyrophyllite with faulting in an examined Manning Canyon outcrop in the near-by Oquirrh Mountains indicates localization of the hydrothermal solutions along fault planes.

In most of the pits bleaching by surface weathering extends to depths of approximately 30 feet. This bleaching, however, has no apparent relation to the distribution of the pyrophyllite.

CELLULAR CONCEPT OF PATTERNED GROUND*

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A cellular concept provides a systematic genetic scheme to which existing hypotheses for arctic-type ground pattern formation may be referred. Three fundamental circumstances are postulated to control ground patterns: formation of soil cells, frost action and cryostatic pressure within cells, and surficial modification.

Cells are discrete soil units of any size bounded by physical discontinuities. Discontinuities result from contraction cracks and juxtaposed soils of differing thermal and mobility characteristics. Discontinuities create differences in thermal regime between cells and their surrounding media such that cells are move favorable sites for frost action and cryostatic release.

Principal elements of frost action are soil expansion by ice-lens growth and other means, and cryostatic intrusion of unfrozen mobile soil into the frozen active layer. The degree of frost action within cells depends on their frost susceptibility, which ranges from negligible in coarse well-drained soils to predominant in fine soils.

Primary agents of surficial modification are runoff, high winds, and vegetative cover. Significant modifying factors are slope, exposure, available ground moisture, and gravity. Complex interactions between agencies and modifying factors sculpture frost-affected soil cells into sorted nets, vegetation stripes, solifluction crescents, and so on.

Sizes and shapes of features vary depending upon which fundamental circumstance is dominant. Similarly, either cracking or frost action is superimposed upon the other. Thermal contraction cracks are primarily responsible for large polygons; frost action is dominant in soil-circle and net formation. Recognition of the dominant circumstance, developmental stage, and modifications is necessary to understand individual patterns.

STRATIFIED MESOZOIC ROCKS IN THE EASTERN PART OF THE MOJAVE PROVINCE

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In the Soda Mountains west of Baker, California, there occurs at least 1675 feet of Lower Triassic (?) limestone, shale, and sandstone disconformably overlain by about 7000 feet of Triassic-Jurassic (?) andesite flow breccia and interbedded sandstones. Original thicknesses may have been much greater, for the beds are limited by faults and granitic intrusions.

Major lithologic subdivisions are:

	Feet
(4) Andesite flow breccia, pyroclastic rocks, interbedded with andesitic and quartzose sandstones; extreme lateral and vertical variation in interbedding. Varicolored cross-bedded sandstone in lenses up to 300 feet thick constitutes almost half the unit.	7000+
(3) Shale, gray, locally green and red, silty and sandy toward top.	650

* By permission of the Corps of Engineers, U. S. Army.

(2) Limestone, gray, finely crystalline, in part nodular, shaly, and fossiliferous; interbedded with shale, gray, green, and red. Beds range from 2 to 35 feet in thickness. 575

(1) Limestone, gray and buff, containing minor amount of limey shale in beds half an inch to 2 feet thick. 450+

Larval gastropods, *Hydrobia* (?), in Unit 2, discovered by J. F. McAllister and examined by C. W. Merriam, are almost certainly Early Triassic, similar to fauna in the Lower Triassic of the Providence and Inyo ranges. Thick sandstone lenses in Unit (4) strongly resemble Lower Jurassic (?) Aztec sandstone at Mountain Pass. The andesites are similar to Triassic-Jurassic volcanic rocks in the Mojave Province.

Interfingering volcanic and sedimentary lithologies in Unit (4) constitute a transitional facies between environments of dominantly volcanic accumulation southwestward and of sandstone deposition northeastward during parts of the Triassic and Jurassic periods.

TRAINING GEOLOGISTS FOR CAREERS IN ENGINEERING GEOLOGY

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Engineering geology is a specialized field for which the average geology major is woefully underprepared. The engineering geologist expresses geologic facts and interpretations in concepts usable to the civil engineer. Briefly, the qualified engineering geologist must have a selective background of training and/or experience in engineering design and construction. The Army Corps of Engineers has found it necessary to conduct selective on-the-job training for most new geologists. This training period could be greatly shortened and made far more meaningful to the newly hired geologist if he were to have undergraduate training in civil-engineering subjects.

Many college-level institutions offer courses containing subject matter designed to outline the engineer-geology field to the undergraduate. A few universities and engineering schools offer complete 4-year undergraduate courses leading to degrees in engineering geology. Typical is the Colorado School of Mines. Its curriculum has basic and advanced geologic coverage amounting to 42 semester hours In addition 39 hours are required in civil engineering and related fields.

The basic purpose behind collegiate training is to qualify the graduate in a specific calling. Specific rather than general-background training will help the individual geologic trainee to attain this goal more closely.

STRUCTURAL FEATURES OF PARTS OF NORTHERN UTAH AND SOUTHEASTERN IDAHO

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Numerous structures of regional importance are recognized in northern Utah and southeastern Idaho between Ogden, Utah, and Montpelier, Idaho. The Taylor and Ogden thrusts and the Willard thrust are well exposed near Ogden. The Wasatch fault zone parallels the western front of the Wasatch Range, and high-angle faults seem to mark the western front of the Bear River Range. The Bannock thrust parallels the eastern side of the Bear River Range although the critical area of Mansfield is north of Montpelier, Idaho.

Thrusts of this region are attributed to compression of the Laramide orogeny. Eastward movement on the Bannock thrust diagonally opposes westward movement on the Willard thrust, confirmed by small-scale features and areal requirements. Eardley has taken the eastward dip of the Taylor and Ogden thrusts as suggestive of westward movement, whereas folding east of the Z-fold in Ogden Canyon indicates eastward movement. Thrusting, therefore, seems to have been in opposite directions owing to regional compression. The observed thrusts may be related to vertical movements resulting from Laramide compression with the fundamental stress axis, nevertheless, aligned about east-northeast.

Some high-angle faults of northerly trend show pronounced drag opposing fault displacements of considerable magnitude. At one point slightly disturbed Tertiary beds are faulted against greatly disturbed Paleozoic rocks. These and other relations indicate that initial high-angle faulting occurred in association with regional compression, probably of Laramide affinity. Later movements on these faults may account in part for Basin and Range faulting, as usually understood.

STRATIGRAPHY OF FRONTIER FORMATION, POWDER RIVER BASIN, WYOMING

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The Frontier Formation (Upper Cretaceous) in the Powder River Basin of northeastern Wyoming is a sandstone and shale sequence defined at the top by the Wall Creek Sandstone Member and at the base by the Clay Spur Bentonite.

The Frontier Formation is of Belle Fourche (Cenomanian), Greenhorn (Cenomanian and Turonian), and Carlile (Turonian) age. Correlation of the Frontier Formation with the Belle Fourche Shale, Greenhorn Limestone, and lower Carlile Shale of the Black Hills is based on stratigraphic position, lithologic similarity, and faunal succession.

A sandstone facies in the southwest Powder River Basin interfingers with a shale facies to the north and with a shale and shale-limestone facies to the east.

The Frontier and equivalent formations were deposited chiefly in an epineritic shelf environment. Abrupt change from siliceous Mowry Shale to silty shale in the lower Frontier is attributed to increased rate of deposition and slight increase in water temperature.

Sandstone distribution indicates that the main Laramide structural features were present in embryonic form during the deposition of Frontier sediments and that most of the sediments entered the basin area from the southwest. A minor supply of sediment, including chert and andesite porphyry cobbles, entered the basin from the northwest Kaycee area during late Belle Fourche time. Increased rate of subsidence brought deposition of shale and chalk above the Frontier sediments.

RECONNAISSANCE OF KOYUKUK BASIN, ALASKA, VIA HELICOPTER

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The Koyukuk basin is located in western central Alaska on the Koyukuk and Yukon rivers and is flanked on the north by the Brooks Range geanticline, on the west by the Chukotskiy-Seward uplift, on the southeast by the Ruby geanticline, and on the southwest by the Bethel basin.

The basin preserves approximately 25,000 feet of Cretaceous sedimentary rocks. Faults and intrusions bordering the basin obscure stratigraphy below the Cretaceous. The Koyukuk Group (Neocomian) includes beds of graywacke, conglomerate, slaty shale, brown mudstone, volcanic breccia, and basalt. The Ungalik conglomerate (lower Albian) grades from boulders to pebbles near the base and is interbedded near the top with sandstone and black shale. The Shaktolik Group (upper Albian) is divided into Units A, B, C, and D and consists of beds of gray to black shale, indurated to friable salt-and-pepper sandstone, graywacke, coal, chert and quartz pebble conglomerate, and siltstone. Extrusive rocks are exposed in the Hogatza uplift at the center of the geosyncline; this uplift divides the geosyncline into the west and east segments.

A field party and helicopter crew were maintained at Koyukuk village by the Geophoto Services under contract with Texota Oil Company. The author was in charge of exploration for the company and toured the basin by helicopter and river boat. U. S. Geological Survey publications have been valuable guides in connection with air photos and uncontrolled mosaics. Photogrammetric maps are now in proof.

COMPARISON OF MARINE AND LACUSTRINE SEDIMENTATION

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The sedimentary processes and products of large lakes exhibit striking similarities to those of the ocean. The areas and depths of larger lakes permit the function of many processes also active in the ocean, including wave action, littoral and turbidity currents, delta building, biohermal growth, and accumulation of such pelagic sediments as oozes and fine-grained pyroclastics. The sediments of Lake Bonneville (dystrophic), Great Salt Lake (oligotrophic), and the Eocene Uinta-Gosiute Lake (eutrophic) are described and compared with marine sediments. Faunas of the lacustrine and marine environments are also compared.

Results of this study indicate that greatest similarities of lithologic types and deposits occur in the near-shore environments, and that greatest differences occur in the nature of the pelagic sediments, particularly the organic oozes. Marine and lacustrine environments usually possess distinctively different faunas, and the differentiation of lithologically similar marine and lacustrine sediments in subsurface sample or isolated outcrop can best be done on the basis of fossil content. Although marine sediments generally cover much larger areas than do their lacustrine counterparts, lake sediments in many areas accumulate in subsiding basins to such thicknesses and in such dimensions as to be comparable to intracratonic basins (parageosynclines).

STRUCTURE OF CROSS MOUNTAIN, MOFFAT COUNTY, COLORADO

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Cross Mountain represents one of the geological structures transitional from the east-west trend of the Uinta Mountains of Utah to the north-south trend of the Sawatch Mountains-White River Plateau of Colorado. Cross Mountain is a doubly plunging anticline striking N. 15° W. and is more or less representative of Uinta Mountain structure in that it is flat-topped and has steeply dipping flanks. The flanks include longitudinal, rotational reverse faults with hinge points (or poles) of rotation diagonally opposed northwest and southeast. The angle of rotation on the western fault, the Cross Mountain fault, is approximately 10°, while the rotational angle on the eastern fault is on the order of 1°. The northern end of the mountain is marked by a series of five normal, transverse faults, the throws of which range up to 300 feet. The southernmost two transverse faults merge into a strike fault on the west which is en echelon to the Cross Mountain fault. It is suggested that the stresses responsible for the Cross Mountain structure are to be ultimately resolved into an easterly directed stress at the southern end and a westerly directed stress at the northern end.

UNFOLDING

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Unfolding is defined as deformation that considerably reduces or obliterates previous folds. It appears more or less self-evident that if an area has been folded more than once the later actions may be opposite in magnitude. Thus, upfolds may be later downfolded, and downfolds may be later upfolded.

Refolding, which has been frequently recognized and described, often partly reduces previous folds—although it more commonly enlarges them. Much refolding is transverse and reduces in places the magnitude of previous folds. In such instances refolding may be considered as a type of unfolding.

Probably many anticlines subside at least slightly after relaxation of the pressures that formed

them. However, whether a domed area could be flattened upon removal of the deforming pressure is conjectural. Are there areas of presently uniform low dip that formerly were marked by domes? Could they be recognized?

Unfolding might result from (1) gravity, (2) reversal of direction of vertical pressures, (3) reorientation of lateral stress axes, and (4) migration of folds.

JURASSIC STRATIGRAPHY IN THE ELK RANGE, WEST-CENTRAL COLORADO

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Jurassic rocks 450–500 feet thick occur on the west flank of the Elk Range between Schofield Park and Crested Butte, west-central Colorado. Around Almont and Carbondale, at the south and north ends of the range, respectively, these rocks are between 550 and 775 feet thick. Only 325 feet, however, is present on Coal Creek west of Redstone.

From 55 to 85 per cent of each section belongs to the uppermost green and purple Morrison Mudstone Member. Interbedded argillaceous limestone, siltstone, and sandstone lenses generally are not traceable for more than 2–3 miles. Usually the mudstone member is underlain by a 20- to 80-foot member characterized by light-gray, nonmarine limestone. Interbedded mudstone is abundant in the limestone north of Schofield Park; the member is absent at Almont.

The basal Jurassic, fine to medium, buff to white sandstone is exceptionally thick and prominently cross-bedded, accounting for the thicker Jurassic section near Carbondale and Almont. North of Crested Butte thin, fine clastic and carbonate rocks assigned to the Curtis (?) Formation divide the basal sandstone and separate the Entrada Sandstone from the overlying basal Morrison Sandstone Member. The Curtis (?) Formation was not recognized at Almont, and the entire 178 feet of cross-bedded sandstone is referred to the Entrada Sandstone. Around Redstone the Curtis (?) Formation is also absent, but criteria for distinguishing the basal Morrison Sandstone from the Entrada Sandstone are not apparent.

PETROLOGY AND STRUCTURE OF ANTELOPE ISLAND, DAVIS COUNTY, UTAH

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Antelope Island, the first range west of the central Wasatch, is nearly surrounded by Great Salt Lake. Rocks are predominantly Precambrian of two ages. The older sequence consisting of 20,000 feet of schists, amphibolites, and metaquartzites has been correlated with the Farmington Canyon complex of the central Wasatch and is divided into three unnamed units. The oldest is composed of 4207 feet of quartzo-feldspathic schists with interbedded amphibolites. Above lies 2583 feet of microcline-rich mica schists, and the remaining 13,000 feet consists of predominantly fine-grained quartzo-feldspathic schists with subordinate amounts of amphibolite and metaquartzite.

The younger sequence is correlated with the upper part of the Big Cottonwood Series of the south-central Wasatch and consists of 1050 feet of tillite, dolomite, slate, and quartzites. These beds occurring chiefly at the northern part of the island lie with a gentle northwest dip unconformably on the Farmington Canyon complex.

The Wasatch Group of Tertiary age is composed of conglomerate and fresh-water limestones with included Madison Limestone and Big Cottonwood Series quartzite boulders and rests unconformably on the Farmington Canyon complex. These included boulders suggest that the Madison was probably deposited directly on the Big Cottonwood Series and also that Antelope Island was the center of the early Paleozoic Northern Utah Highland.

The Farmington Canyon complex forms a doubly plunging, north-south anticline broadly arcuate toward the east, the crest of which is on the west side of the island.

PRIMARY STRUCTURES OF THE COLUMBIA RIVER BASALT FLOWS, SOUTH-CENTRAL WASHINGTON

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The Mio-Pliocene Columbia River basalt flows (Yakima Basalt and Wenas Basalt formations) in south-central Washington are tabular bodies of tholeiitic flood lava on the order of 100–200 or more feet thick that can be traced for hundreds of square miles. In general the flows consolidated at rest from an essentially fluid condition; therefore they are rarely pahoehoe or aa. Some flows forming lithologic sequences may represent essentially contemporaneous flow units. Interlensing flow units were formed locally because of viscous accumulation. No flow feeders were found in the area of approximately 2000 square miles studied.

The normal sequence of structures from top to bottom in flows that consolidated from a fluid state consists of a zone with roughly columnar jointing and spherical vesicles, a zone of close-spaced columnar or blocky jointing, and, in the main body of the flow, columnar jointing spaced on the order of 2–10 feet. Variations are sinuous columnar jointing, extensive basal jointing, and platy and slabby jointing either inclined or basal and usually in combination with columnar jointing.

Flows that consolidated during and after viscous movement are characterized by drawn-out vesicles, arcuate columns, and clinker at the tops. One such flow that covered wet sediments has an exceptionally thick accumulation of clinker injected by dikes from the main mass. Fluid flows that entered water or covered wet sediments formed pillow palagonite.

GEOLOGY OF THE BIG CREEK QUADRANGLE, CENTRAL IDAHO

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The Big Creek 15-minute quadrangle, in the center of the Idaho batholith, displays roughly equal parts of three main rock units: metasediments referred to the Belt Series (Precambrian), intrusive granitic rocks of the batholith (Cretaceous), and Challis volcanics (Tertiary). Patches of post-Belt, pre-batholith volcanic rocks (Casto? volcanics) are present. A swarm of Tertiary dikes cuts longitudinally across the quadrangle, mostly occupying a sheared, silicified zone in granodiorite. Deposits of scheelite, huebnerite, sulfides, and sulfosalts, locally carrying precious metals, are present in this and other silicified zones.

Quartzites, "argillites," and limestones of the Belt occur in synclinal roof pendants whose axes trend north-northwest or northwest, plunging either northwest or southeast. Major folds range from upright, open, with vertical axial planes, to overturned, isoclinal, with axial planes nearly horizontal. Pre-batholith mafic dikes follow minor structures genetically related to these folds. Attempts to determine the absolute age of the dikes, and thus fix the minimum age of the folding, have failed. Metamorphic zones imposed on Belt rocks by the batholith range from biotite to sillimanite; intermediate zones are poorly represented.

The chief batholithic rocks are granodiorites. Other rocks include diorite, syenite, alaskite, and microcline-rich granite. Near wall rocks, xenoliths are common; migmatites are not abundant. Internal structure and gross relations suggest that the larger granodiorite masses were emplaced by discordant upward (?) movement of magma, accompanied in marginal zones by sheetlike injection of more mobile granite and syenite. The largest area of interlayered granites and metasediments is apparently restricted to the contact zone between two major Belt units.

FORELAND TECTONICS OF WYOMING

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Asymmetrical anticlines in the state of Wyoming can be classified into two main categories: flank asymmetrical anticlines, primarily in which the vertical plane dips more steeply than 80°; and axial asymmetrical anticlines in which the axial plane dips less than 80°. In addition to axial-plane-dip classification, there are other diagnostic features which are only applicable to each type of anticline. The characteristics of each are due to their respective tectonic formation.

Regional tectonics can be resolved into four distinct times of movement which are reflected in the surface rocks. These are separated into their chronological order.

STRATIGRAPHIC AND LITHOLOGIC CONTROLS OF URANIUM DEPOSITS IN THE MONUMENT HILL AREA, CONVERSE COUNTY, WYOMING

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Uranium deposits at Monument Hill in the Southern Powder River Basin are in the lower Wasatch Formation of Eocene age. Detailed geologic mapping and other studies have indicated that lithology and stratigraphy have influenced the processes of uranium transportation and deposition. It is believed that the uranium was transported by artesian ground waters flowing through these sedimentary rocks.

The major ore controls appear to have been stratigraphic and lithologic; many of the same controls influence ground-water movement. Stratigraphic control was exercised by differential permeability of the formations, by the regional dip of the contact between Fort Union (Paleocene) and Wasatch formations (as arbitrarily defined in the course of this investigation), and by the topography of the erosional disconformity at the top of the Fort Union Formation. Lithologic controls include differential permeability and porosity of the fluvial Wasatch Formation sandstones and the carbonized plant content of favorable sediments.

The most significant localizing control of uranium deposits is thought to be the impedance of laterally flowing mineralizing ground waters in the Wasatch Formation as effected by features of the underlying surface of disconformity. Deposition appears to have taken place where there was a general coincidence of favorable Wasatch lithology and topographic lows on this surface.

INVESTIGATION OF THE BASAL ASH OF THE ARIKAREE FORMATION IN NORTHERN SHANNON COUNTY, SOUTH DAKOTA

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The basal volcanic ash of the Miocene Arikaree Formation, in the Big Badlands of South Dakota, is described as a new member. This conspicuous white ash ranges from 0 to 55 feet in thickness. Lying unconformably on the upper Brule Formation of Oligocene age, the member has a strike of N. 49° E. and a regional dip of 18.8 feet per mile to the southeast.

A possible source of the rhyolitic ash may have been the volcanoes of the Yellowstone region and the Colorado Rocky Mountain region.

Vertebrate fossil localities of the South Dakota School of Mines have been located with respect to the member.

Investigation of the pipe concretions, found in localized areas, within the ash, and the associated minerals of the clastic dikes in other areas suggests that hot-water springs were present at one time in the region now known as the Big Badlands of South Dakota.

STRUCTURAL GEOLOGY OF THE PROMONTORY RANGE, BOX ELDER COUNTY, UTAH

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The Promontory Range consists of Precambrian phyllites, slates, metamorphosed andesitic flows, and quartzites (7400+ feet); Cambrian quartzite, shale, and carbonates (11,100 feet); Ordovician carbonates, shale, and quartzite (2100+ feet); Silurian dolomite (1600 feet); Devonian dolomite (1500+ feet); Mississippian limestone and sandstone (2200+ feet); Pennsylvanian shale, sandstone, and limestone (4000+ feet); and unconsolidated Quaternary deposits.

The Middle Canyon fault, a northeasterly trending normal fault, divides the Promontory Range into two structural blocks. The southern block, 11 miles long, consists of four large, steeply tilted fault blocks which have been rotated with respect to each other. Folding is inconspicuous. The faults conform roughly to north-south and east-west systems and have almost linear traces.

The faults of the northern block have curvilinear traces yet conform more closely to north-south and east-west systems. The strata in these fault blocks generally dip gently eastward and have not been rotated. Tight folding is locally common, but no large anticlinal or synclinal folds are present.

With the exception of one reverse and one overthrust fault all displacements in the range are normal. A large border fault may be present along the western side of the range, but present evidence argues against the possibility of one along the eastern side.

Probable sequence of structural events: (1) overthrusting from the west; (2) folding in the northern block along north-south axes; (3) reverse faulting (north-south system); and (4) normal faulting (north-south system generally precedes east-west system) and rotation of fault blocks. The absence of Mesozoic and Tertiary deposits precludes accurate dating of the orogeny.

SEVY FORMATION, LOWER DEVONIAN, IN THE CORDILLERAN MIOGEOSYNCLINE

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The Sevy is typically fine crystalline to microcrystalline tan dolomite which weathers with a very light-gray surface. It occurs in beds from 5 inches to 2 feet thick and may be finely laminated. Sedimentary breccias, conglomerates, and soft-sediment deformations are common. Quartz sand grains occur throughout the unit but are concentrated near the top.

The unit is remarkable in being recognizable through an area of 100,000 square miles in California, Nevada, Utah, and Idaho. Its average thickness is 500 feet. Throughout most of its extent, the Sevy overlies Silurian Laketown Formation and is overlain by the Simonson Formation, Jefferson Formation, or similar middle Devonian strata.

It is thought that the Sevy originated as a primary evaporitic dolomite with redeposited dolomite debris and was formed on extensive mud flats at or near sea level. The quartz sand is considered to have been derived in large part from erosion of middle Ordovician quartzites along the eastern margin of the miogeosyncline. Streams carried the sand to the edge of the flats. Later the sand grains were probably blown across the periodically emergent flats and entrapped in shallow pools or areas of unhardened sediment. At the western margin of the Sevy area, the sands are thickest possibly as a result of longer stands of water.

SUBSURFACE PERCENTAGE OF SANDSTONE AND SILTSTONE IN LOWER PART OF GREEN RIVER FORMATION, CENTRAL AND EASTERN UINTA BASIN, UTAH

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The oldest unit of the Eocene Green River Formation, the black shale facies, is 1080 feet thick near Duchesne, Utah. It thins to less than 200 feet approaching the eastern and southern edges of the

basin. Sandstone and siltstone isopercentage lines are irregular in pattern but generally parallel the margins of the basin. Values range from 4 per cent near Duchesne to more than 25 per cent along the south-central and eastern margins. The amount of increase along the northeastern edge is indeterminable because this unit is inseparable from overlying beds.

During "black-shale-facies time" the Uncompahgre uplift was a major source area; the Douglas Creek arch and the Uinta Mountains, bordering the northern and eastern margins, were minor source areas.

The overlying delta facies of the Green River Formation ranges in thickness from approximately 800 to 1700 feet in the central and eastern Uinta basin region. Sandstone and siltstone isopercentage lines roughly parallel the margins of the basin, and values range from 5 per cent in the central portion to more than 60 per cent in the south-central part. The percentage increase along the northeastward edge is indeterminable because the delta facies cannot be precisely differentiated from overlying and underlying beds. On the eastern edge, along the west flank of the Douglas Creek arch, relationships are not clear.

A major source area, probably related to the Uncompahgre uplift, was present at the southeast during "delta-facies time." Minor source areas, a part of the Uinta Mountain uplift, bordered the northern and northeastern edge.

PALEO-WIND DIRECTIONS IN LATE PALEOZOIC AND EARLY MESOZOIC TIME ON THE COLORADO PLATEAU AS DETERMINED BY CROSS-STRATA

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During the past 8 years data have been collected on cross-stratified sandstone units of probable eolian origin on the Colorado Plateau. These deposits consist of large- and medium-scale, wedge- and subordinate lenticular-shaped planar and trough sets of steeply dipping cross-strata and associated high-index ripple marks.

Such sandstones associated with marine strata probably represent beach deposits reworked by wind before lithification. Sandstone deposits not associated with marine strata may have originated as marginal marine deposits or may represent reworked continental beds. Landward accumulation of sand is probably analogous to conditions on the Libyan Desert today. Cross-strata interpreted as fluvial in origin are associated commonly with eolian-type sandstone and may represent mingling of wind-blown sand and fluvial sediments in continental basins. In general, these eolian sandstones thicken in the downwind direction.

Dip orientation of cross-strata indicates that late Paleozoic and early Mesozoic winds on the Colorado Plateau were relatively constant and blew in a southerly direction. The high consistency in dip directions of cross-strata in eolian deposits is probably the result of winds with great regularity and strength similar to our present-day "Northeast Trades." It is thought that in late Paleozoic and early Mesozoic time the northern hemisphere trade-wind belt in this area was 10° to 20° farther north than at present. Tropical-type fossil plants found in continental sediments of the same age are similarly transposed from the present equatorial zone.

ALUMINUM CLAYS OF NORTH DAKOTA

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North Dakota clay deposits are of both glacial and nonglacial origin. This paper deals with investigations of the nonglacial clays of Tertiary age, especially clays immediately underlying the lignite beds. Alteration and modification of clay properties and minerals by the overlying organic matter occurs under certain conditions.

Underclays are present below many of the lignite seams. Clay samples were collected in that part of North Dakota west and north of the Missouri River. Generally, samples were collected laterally

over the width of the exposure; in other localities samples as far as 15–20 feet below the lignite were taken. Occasionally overlying clays were sampled.

Hand-specimen descriptions, petrographic descriptions, differential thermal analyses, and chemical analyses of these samples were made. Samples ranged from high-grade clay through silty clays or silty shales. Many of the clays were somewhat lignitic. Color ranged from white or light gray to dark gray and brownish gray. Many of the samples were micaceous. Simple benefaction could remove much of the sand, silt, lignite, and mica.

Chemical analyses indicate a varied composition. Some analyses show almost 25 per cent Al_2O_3 in the sample. The amount of silica depends upon the amount of silt present. One of the better clay samples, on analyses, yielded Al_2O_3 24.6%; SiO_2 65.8%; iron oxides 1.3%; and miscellaneous 8.3%. Differential thermal analysis indicates that the principal clay mineral is illite. Gibbsite and related minerals were not abundant.

GEOLOGICAL AND GEOPHYSICAL STUDIES, RED RIVER VALLEY, MINNESOTA AND NORTH DAKOTA

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A series of geological resistivity studies has been completed in the Red River Valley area of Minnesota and North Dakota. The principal area of the survey extended from Fargo, North Dakota, to several miles east of Hawley, Minnesota.

The Red River Valley is part of the bed of glacial Lake Agassiz. Near the center of the Valley several hundred feet of glacial lake beds overlies an irregular weathered granite basement. The lake beds accumulated in glacial lakes during two or more glacial periods. In the central portion of the Valley, well logs show clays and silts with varying water content and varying degrees of induration. In places a relatively sharp change in type and character of deposit, water content, and/or degree of induration marks the boundary between successive glacial deposits. Buried among the lake beds are bars and sand lenses which form aquifers from which farms and towns in the area secure water. Around the margins of the valley are abandoned lake beaches and bars, reworked glacial debris, and deltaic deposits. Farther east are glacial outwash, moraine, and drift accumulations.

Surveys were run over various types of deposits in the lake basin, along its margins, and well back from the edges to determine the applicability of electrical methods of prospecting for locating sand, gravel, bedrock and aquifers in the region and for interpreting the geological and subsurface conditions. Resistivity curves were determined, and interpretation of the curves was checked against bore holes and other geology.

SUGGESTED MODIFICATION OF PRE-BELTIAN HISTORY IN SOUTHWESTERN MONTANA

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Earlier workers in southwestern Montana have postulated the following pre-Beltian historic sequence: (1) formation of Pony metamorphic rocks; (2) deposition of Cherry Creek sediments; (3) metamorphism of Cherry Creek sediments (in which Pony rocks underwent still further metamorphism).

Recent mapping in the Tobacco Root Mountains indicates that Pony metamorphic rocks (near the type locality) overlie Cherry Creek metamorphic rocks. The two groups appear to be concordant and to have isoclinally folded compositional layers, closely similar textures, and axial-plane foliation. Ortho-amphibolite sills and dikes cut the foliation in both Pony and Cherry Creek. These fine-grained sills and dikes have a weak foliation parallel to the foliation in the enclosing coarser-grained metamorphic rocks and locally form large boudins. The axial planes of the isoclinal folds (and hence the foliation) are deformed into broad open upright 45-degree to 70-degree north-plung-

ing folds. Deformation occurred largely through slip along existing foliation planes. Because of this, the ortho-amphibolite dikes and sills acquired foliation parallel to that of the enclosing rocks and were locally stretched into boudins.

It appears that the Pony and Cherry Creek metamorphic rocks crystallized in an early period of pre-Beltian metamorphism in which the rocks were deformed into recumbent (?) isoclinal folds. Cherry Creek seems to be older than Pony in the Tobacco Root Mountains. Following metamorphism, basalt sills and dikes were injected. Folding of the foliation took place in a post-basalt period of amphibolite-facies metamorphism, and the basalts were converted to ortho-amphibolites.

SOME SUBMARINE MASS MOVEMENTS

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Submarine toreva blocks are well developed in the Leonardian Bone Spring Limestone in the Guadalupe and Delaware mountains of Texas. Similar blocks are also well exposed in the dark Leonardian siltstone in the northern Chinati Mountains, Texas. Glide folds are associated with the blocks and show movement into the deep Delaware and Marfa basins. Similar folds are exposed in the Mississippian Great Blue Limestone in the Oquirrh Mountains and in Quaternary sediments in central Utah Valley. Initial sedimentary dips of approximately 2° are indicated as the critical glide angle for such slumps. Leonardian and Guadalupian submarine debris falls and associated deposits of turbidity currents are well demonstrated in the Guadalupe, Apache, and Chinati mountains.

BURRO CANYON FORMATION IN THE SLICK ROCK DISTRICT, COLORADO

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Recent studies in the Slick Rock district, Colorado, have disclosed new information concerning the Burro Canyon Formation. The salient features are: (1) the absence of the upper part (shale, limestone, and chert) of the formation near the crest and on the south flank of the Dolores anticline; (2) the variation in the contact with the overlying Dakota Sandstone, which is conformable but sharp in Disappointment Basin, and disconformable elsewhere; (3) interfingering with the underlying Brushy Basin Member of the Morrison Formation; (4) a fossil collection containing *Protelliptio douglassi*, *"Unio" farri*, and *Frenelopsis varians*, which verifies the Early Cretaceous age of part of the formation.

RIB-AND-FURROW, A PRIMARY DIRECTIONAL STRUCTURE OF SEDIMENTARY ROCKS

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Cross-bedding, ripple mark and current lineation have been described as useful criteria of current direction in sedimentary rocks. Another feature, termed rib-and-furrow, has been noted but not yet fully described. As seen on surface exposures of water-laid sediment it consists of alternating, crudely formed ridges and shallow rounded depressions running parallel with the flow direction of the depositing currents. The ridges are usually rather sharp, and the distance from crest to crest averages about 2½ inches.

Internally, rib-and-furrow consists of small imbricating lenses and wedges inclined down current. These individual lenses may be flaked off and are more or less equidimensional and irregular in shape. Cross-section views of rib-and-furrow are similar to ripple-marked material.

Manner of formation of rib-and-furrow is not understood. No published record of its formation in recent environments has been found, but it has been noted in rocks of Paleozoic, Mesozoic, and Cenozoic age. Field evidence shows that the hydrologic conditions of formation are similar to those of ripple formation and that a general increase in current velocity transforms the bottom markings from ripple mark to rib-and-furrow. It is suggested that under certain conditions the water moves forward in counter-rotating spiraling masses and that the ridge forms where sides of opposing cylinders move upward, and the furrow forms where they move downward. Air currents of this nature have been described, and the mechanics of formation may be similar.

GEOLOGY OF THE KINSLEY QUARTZ MONZONITE STOCK, ANTELOPE RANGE, EASTERN NEVADA

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Mining has produced moderate amounts of copper, tungsten, molybdenum, silver, and lead from several small mines situated near the quartz monzonite stock at Kinsley, Nevada. This district is located at the south end of the Antelope Range in eastern Nevada about 25 miles due west of Gold Hill, Utah. The outline of the stock is roughly circular and covers about 1 square mile. The wall rocks are gently dipping, little-disturbed Upper Cambrian limestones and shales.

Most of the quartz monzonite is medium-grained and of similar composition throughout except in places near the margin where the plagioclase is anorthitic. A unique feature is a series of nearly vertical quartz latite porphyry dikes cutting the stock at an angle of approximately N. 40° E.; they range in width from a foot to 200 feet. Some extend through the stock without a break and into the sediments as much as 1300 feet on either side. Contact effects consist of a wide bleached zone in limestone on the northeast and southwest margins with a few irregular tactite areas. The metal mineralization is confined principally to areas in limestone near the ends of the quartz latite porphyry dikes.

AUTHIGENIC BROOKITE IN CRETACEOUS GALLUP SANDSTONE, GALLUP, NEW MEXICO*

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Brookite-bearing sandstone near Gallup, New Mexico, was found by a Navajo Indian while prospecting for uranium. Because of the high content of zircon in the sandstone the radioactivity is about 3–5 times above background. The sandstone was referred to locally as the "Gallup titanium deposit" after the titania minerals were found to be important constituents of the sandstone.

The minerals of the sandstone were identified by immersion and X-ray powder diffraction methods, differential thermal analysis, and by use of the electron microscope. The unusually fine grain of some of the minerals prevents determination of relative proportion of the minerals by modal analysis. However, based on a complete chemical analysis of the sandstone, the normative proportion of the mineral molecules in the sandstone was calculated as follows: zircon 7.22%, apatite 0.43%, sphene 0.39%, albite 2.16%, orthoclase 2.24%, montmorillonite 8.67%, spessartite 0.37%, kaolinite 24.20%, ilmenite 2.44%, limonite 13.52%, brookite 27.81%, quartz 8.83%, and H_2O 1.72%.

Leucoxene, which is composed of cryptocrystalline rutile and amorphous substances, has formed at the expense of ilmenite. Brookite is considered to be authigenic because (1) it is formed *in situ* and occurs as small boxworks between other detrital mineral grains, (2) the absence of evidence of hydrothermal activity in the sandstone, and (3) it is formed from the amorphous titania or the cryptocrystalline rutile of the leucoxene. The occurrence of leucoxene is common in rocks, but the occurrence of authigenic brookite in the Gallup sandstone is rather significant.

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* Publication with the permission of the Director, New Mexico Bureau of Mines and Mineral Resources.

FORT UNION FORMATION, WEST FLANK OF THE SIERRA MADRE, CARBON COUNTY, WYOMING

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Surface exposures of Paleocene rocks measured from T. 14 N. to T. 17 N., R. 91 W. and R. 92 W. indicate 1530 to 1750 feet of beds conformably above the Lance Formation and unconformably below the Wasatch Formation.

The Lance Formation includes at the top 600 feet of massive and cross-laminated sandstones. Conglomerates within the sandstone contain Paleozoic limestone cobbles and granite pebbles indicating that the core of the Sierra Madre was exposed.

The contact of the Fort Union and Lance formations is above the massive sandstones and below coal-bearing beds. In the northern part of the area coal accumulation began earlier than to the south, so that the contact is not a time line.

The name Fort Union Formation is applied to two distinctive lithologic units. The lower 700- to 1200-foot unit of sandstones, shales, and thin coal and lignite beds contains an early Paleocene flora and a middle Paleocene fauna. Presence of coals, abundance and nature of leaves, and type of vertebrate and invertebrate faunas is evidence for a humid warm temperate climate and heavily forested lowlands. The upper 860- to 1040-foot unit of noncoal-bearing claystones, shales and sandstones is believed to be Paleocene on the basis of stratigraphic position, as no fossils were found. It is locally conglomeratic.

An angular unconformity between the Fort Union and Wasatch formations is suggested by thickness variations in the upper part of the Fort Union and by divergence in strike of Wasatch and Fort Union formations in T. 17 N.

FRONTIER FORMATION IN THE COALVILLE AREA, NORTHEASTERN UTAH

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The Coalville area is located 20 miles northeast of Salt Lake City and 75 miles southwest of the type area of the Frontier Formation. This formation, of early Late Cretaceous age, is exposed in a series of folds.

Assigned to the Frontier Formation in the Coalville area is 4425 feet of alternating marine (55%) and nonmarine (45%) beds consisting of sandstones and shales with minor amounts of conglomerate and coal.

Based on origin, the formation can be divided into the following four units (descending order):

(4) 2440 feet of marine sandstone and shale with a 635-foot nonmarine sequence in the lower half; an early Niobrara (Coniacian) fauna
(3) 800 feet of nonmarine sandstone and claystones with a 75-foot bed of conglomerate 200 feet from the base
(2) 795 feet of marine sandstone and shale dated as early Carlile (Turonian) and late Greenhorn (Turonian) ages; coal is associated with sandstones near the base
(1) 400 feet of dominantly nonmarine sands and clays (probably Cenomanian).

The Frontier is underlain by the nonmarine Kelvin Formation (Early Cretaceous) at the top of which is a 60-foot bed of Aspen-like fish scale-bearing siliceous shale. The nonmarine Henefer Formation (Late Cretaceous ?) overlies the Frontier.

The upper boundary of the Frontier at Coalville is probably somewhat younger than the top of the formation at its type locality.

The alternating marine and nonmarine sequence was probably produced by an oscillating strand line in a subsiding basin of deposition.

ORIGIN OF THE "CRINKLED" MEMBER OF THE LYKINS FORMATION IN CENTRAL COLORADO

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The "Crinkled" Member of the Lykins Formation in central Colorado is characterized by conspicuous crenulations of its varvelike laminae. Previous investigators have suggested that the crenulations resulted from penecontemporaneous deformation caused by slumping. The presence of early deformational structures is not questioned, but this interpretation fails to explain certain crenulated features common in the member. Excellent exposures in the vicinity of Colorado Springs reveal well-developed stromatolite heads, and the occurrence of similar but less conspicuously developed features in other areas suggests that the member in most places is in part a stromatolitic biostrome.

Published descriptions of the ecology of stromatolites of recent age suggest that the "Crinkled" Member was deposited either on a very shallow marine bottom or on an intermittently exposed tidal flat. In either of these environments the depositional surface in places was covered with a mucilaginous algal mat in which sediments became mechanically entrapped. Most of the sediment is believed to have been clastic carbonate composed of chemically or biochemically precipitated particles reworked by currents. Commonly the carbonates were mixed with silt- and sand-size detrital quartz. Close association of the "Crinkled" Member with gypsiferous deposits implies that the depositional environment was hypersaline.

Laboratory studies, including X-ray and differential thermal analyses, disclose that the "Crinkled" Member is mostly dolomite—contrary to published statements that it is limestone or limy sandstone.

CRETACEOUS TO TERTIARY OROGENY IN THE JACKSON MOUNTAINS, HUMBOLDT COUNTY, NEVADA

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A formation of Early Cretaceous age composed of locally derived clastic rocks, including pebble to boulder conglomerate, siltstone, coarse graywacke, and fine-grained limestone is exposed at several places in the central and northern part of the Jackson Mountains, Humboldt County, Nevada. These Cretaceous rocks were folded and at one place completely eroded before deposition of the next younger unit—a pebble conglomerate composed of exotic pebbles of chert and quartzite derived from rocks of early Paleozoic age. This younger pebble conglomerate may be of Late Cretaceous or Early Tertiary age and may be equivalent to rocks of similar stratigraphic position and lithology exposed over a considerable area of eastern Nevada and western Utah. Both of these coarse clastic formations have been overridden by Permian or older volcanic rocks on a thrust sheet, the dimensions of which are not known exactly but whose remnants are exposed over a 25-mile-long segment of the range. Late Tertiary volcanic rocks exposed in the range are not involved in the thrusting.

The Cretaceous and younger rocks of the Jackson Mountains record a long period or orogenic unrest that included: (1) uplift of the source area of and deposition of the Early Cretaceous rocks; (2) folding and beveling by erosion; (3) deposition of the exotic-pebble conglomerate; (4) thrusting of the old volcanic rocks over the two coarse clastic formations; and (5) later folding, faulting, and erosion to provide the present outline of the range.

RELATIONSHIP BETWEEN PALEOTEMPERATURE AND CARBONATE CONTENT IN A DEEP-SEA CORE

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Core A 172-6 taken at a depth of 4160 meters from the eastern extension of the Beata Ridge by the Lamont Geological Observatory has been spectrochemically analyzed for selected major and minor elements.

A detailed point-by-point comparison of the data thus obtained has been undertaken with reference to published paleotemperature data for the same core at correlative intervals of 10 cm spacing throughout a core length of 9.35 meters.

Since the carbonate content of an ancient sediment is often cited as a clue to the temperature of the sea water at the time of formation of the sediment, a study of the paleotemperature and carbonate-content relationships in this core has been undertaken to examine the validity of this concept for a sea which during the time of most extreme glaciation exhibited a paleotemperature range analogous to those which exist in modern tropic seas.

Previous concepts as to the existence of magnesium as carbonate in deep-sea sediments as well as concepts related to the origin of the manganese in deep-sea sediments are examined in the light of evidence obtained from a study of this core.

RELATION OF PHOSPHORITE DEPOSITS TO GROUND WATER IN BEAUFORT COUNTY, NORTH CAROLINA

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Recent ground-water studies, undertaken by the U. S. Geological Survey in co-operation with the North Carolina Division of Mineral Resources, have delineated phosphorite deposits, regarded as of middle Miocene age, in Beaufort County. These deposits lie unconformably on Eocene limestone and are unconformably overlain by late Miocene marl. The phosphorites, buried beneath strata ranging in thickness from 50 to more than 200 feet, underlie an area approximating 450 square miles. Total thickness of the phosphorite column throughout the area ranges from several feet to nearly 90 feet.

The phosphorites, composed of brown sand-sized collophane (carbonate-fluorapatite) and sand-sized, flat-sided quartz grains with some silt, clay, and organic material, have a median diameter between 1 and 2 on the Phi scale. Chemical analyses show variation in Ca_3PO_4 content from 20 to 66 per cent. Variation in P_2O_5 content, from 8 to 31 per cent, is proportionate to the collophane content.

Chemical analyses of artesian water from the phosphorites reveal significantly greater concentrations of bromine, iodine, and boron in solution than are present in underlying and overlying formations. Such anomalies, if present in other similar terranes, may reveal the presence of buried phosphorites.

Reconstruction of the geologic history of the phosphorites indicates that the deposits were preserved under artesian conditions; no secondary alteration occurred in an unconfined zone having a fluctuating water level. This absence of alteration makes the area a potentially classic one for study of phosphorite genesis.

The depth and size distribution of the material suggests a recovery method utilizing wells constructed to "pump sand".

DEVONIAN STARFISH FROM PENNSYLVANIA

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A new species of *Hudsonaster* has been found in unquestioned Ludlowville beds of the Mahantango Formation near Milford, Pennsylvania. This genus has hitherto been known only from the Upper Ordovician.

The starfish exhibits such "primitive" characters as few heavy plates and no accessory ossicles in the arms or disc. However, the superomarginals almost overlap the inferomarginals from the apical side. This is an "advanced" feature predicted by Schuchert (1915) to be found in forms later than Ordovician.

The associated trilobites, pelecypods, and brachiopods in great numbers in a calcareous siltstone environment indicate warm marine seas. "Storm rollers" indicate shallow water occasionally agitated by strong waves.

ORIGIN OF THE BLUE RIDGE ESCARPMENT DIRECTLY SOUTHWEST OF ROANOKE, VIRGINIA

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The area directly southwest of Roanoke, Virginia, contains numerous features that bear directly on the origin of the Blue Ridge Escarpment. The area includes not only this escarpment between the Blue Ridge and Piedmont, but also the boundary between two more-or-less distinct parts of the Blue Ridge Province—the irregular mountain ridges drained by Atlantic Coast streams and the dissected upland drained almost wholly by streams of the Gulf of Mexico Drainage Basin.

The Blue Ridge Escarpment appears to have been formed as the result of northwestward migration of the asymmetric Atlantic-Gulf of Mexico Divide. However, the only conclusions that can be reached are: (1) the escarpment either could have evolved to its present form as a consequence of migration of the divide or could have been initiated by faulting, differential warping, erosion controlled by differences in rock resistances, or even by marine erosion; (2) if the escarpment was formed by any process or processes other than divide migration, this process resulted in establishment of an ancestral escarpment far southeast of the present escarpment; (3) the present appearance of the escarpment, no matter what its history, is dependent mainly upon erosion along the migrating divide.

PETROLEUM DEVELOPMENT IN SOUTHEASTERN UNITED STATES

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The area discussed comprises the 10 states south and east of the Ohio-Mississippi river system including the Virginias. This region incorporates structural provinces of widely varying types, ranging from salt domes of the Gulf Coast and complex folds of the Appalachians to the gentle folds of the interior basins. Producing geological formations range in age from those of the Tertiary in southern Mississippi to the older Paleozoic rocks of the more northerly areas. There has been active exploration for oil and gas in the region since the days of Drake's discovery well in neighboring Pennsylvania. Important producing areas have been the Paleozoic fields of the Appalachian geosyncline, the Cincinnati arch, the Eastern Interior basin, and the Black Warrior basin, and the Tertiary and Mesozoic fields of the Gulf Coast geosyncline. More recently, production has been developed from other basin areas in southern Florida and southwestern Alabama.

Daily oil production from the region averages 180,000 barrels and represents 2.5 per cent of United States total production. Gas production from Mississippi, West Virginia, and Kentucky in 1956 represented 4.7 per cent of the total marketed in the United States and reached nearly ½ trillion cubic feet. Oil reserves of the region exceed 650,000,000 barrels, and gas reserves approximate 5.5 trillion cubic feet with over 100,000,000 barrels of natural-gas liquids. The number of producing wells, nearly 50,000, represents 8.7 per cent of the United States total.

Active drilling continues throughout the region and in 1956 totaled nearly 3200 wells or more than 5 per cent of the United States total; Kentucky reported over 1900 wells, followed by West Virginia with nearly 700 and Mississippi with 441. Present exploration activities are spread throughout the region, and nearly 45 million acres are under lease. Florida leads with 19,500,000 acres; Mississippi with 8,250,000 is second; Alabama with 7,100,000 is third; West Virginia with 3,100,000 is fourth. With extensive rather sparsely drilled basin areas, particularly in the Gulf Coast geosyncline, smaller basins of Florida and Georgia, the Black Warrior basin, and the Atlantic Coastal Plain, the southeastern states retain many potentialities for important additions to oil and gas production.

X-RAY ANALYSES OF THE CLAY MINERALS FROM SELECTED OUTCROPS OF THE TUSCALOOSA FORMATION, NORTH CAROLINA

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Preliminary field work on the exposed Tuscaloosa Formation in North Carolina indicates that the formation may be subdivided into two lithic units. The basal unit occurs as essentially uniform beds of poorly indurated and poorly sorted sand and clay. Individual beds may be identified by their higher content of either sand, silt, or clay. The upper unit is found nearer the Piedmont border. It occurs as irregular beds of sand, silt, and clay that may vary within short distances both horizontally and vertically. Small lenses of white silty clay are characteristic of this unit.

X-ray analysis of the clay minerals from selected outcrops of the two lithic units shows that montmorillonite and kaolinite are characteristic of the lower unit and kaolinite is characteristic of the upper unit. A small amount of illite occurs with the kaolinite in one of the samples from the

upper unit. A more detailed sampling of the lithic populations of the formation is needed before it can be stated that the clay mineral distribution holds constant for the entire North Carolina Tuscaloosa Formation.

The clay minerals probably originated in the source land and were transported and deposited without much diagenetic change. Different climate, topography, rate of erosion, and amount of volcanic activity in the source land may account for the observed clay-mineral distribution; however, it is not possible to select a unique mode of origin for the clay in the two lithic units.

PARTIAL FUSION OF GNEISS BELONGING TO THE LOWER AMPHIBOLITE FACIES NEAR CHELAN, WASHINGTON

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Anatectic fusion of gneisses supposedly begins only after the highest grade of regional metamorphism *i.e.*, the granulite facies, has been reached. Near Chelan, Washington, however, neomagmatic quartz diorites appear to have formed by the partial fusion of gneiss belonging to the lowermost amphibolite facies.

Where the regionally metamorphosed gneiss, consisting of plagioclase (An_{30}) + quartz + green hornblende + biotite + epidote, became anatectic the first-formed melt had the composition: quartz + (some) plagioclase. On crystallization this melt formed interstitial quartz, in contrast to podlike segregations in the gneiss. Plagioclase, zoned from An_{50} to An_{18}, solidified as euhedral overgrowths enclosing cores of corroded unzoned metamorphic plagioclase (An_{30}). Relict hornblende is strongly sieved, as in the parent gneiss. The anatectite forms diapir intrusions into the gneiss; elsewhere the two are broadly gradational, and lineation continues undeviated through both gneiss and anatectite.

Hypersthene is absent from the gneiss. Its appearance would probably mark the threshold of the granulite facies. The "hypersthene isograd" for this rock is approximated by the reaction: pargasite + quartz $\rightleftharpoons$ hypersthene + Al-diopside + plagioclase + water.

Fusion within the amphibolite facies (*i.e.*, before appearance of hypersthene) might be possible, though at comparatively high temperature (possibly ~700°C.), under conditions of high water-vapor pressure ($P_{H_2O} \approx P_{total}$). Melting temperature would be minimum, whereas the "hypersthene isograd reaction" temperature would be maximum, possibly above the fusion surface. During "dry" metamorphism ($P_{H_2O} \ll P_{total}$) the granulite facies field would be entered before fusion begins, because the "hypersthene isograd reaction" temperature is lowered, and the melting temperature greatly raised.

EASTERN KENTUCKY COAL STUDIES BY THE U. S. GEOLOGICAL SURVEY—A PROGRESS REPORT

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Current eastern Kentucky coal studies by the U. S. Geological Survey include geologic quadrangle mapping to show the extent and thickness of coal beds and an appraisal of coal resources of the entire field. Reports on four 15-minute and four 7½-minute quadrangles have been published, and reports on four additional quadrangles are in preparation.

Since 1953 the major objective of the studies has been the appraisal of the coal resources. This appraisal was based principally on geologic reconnaissance mapping augmented by information obtained from coal-mining companies and from published reports. The data gathering is complete, and a report is in preparation. The work could not have been done without the co-operation of coal companies and the Bureau of Mines. Preliminary examination of the accumulated data suggests that the new estimate of coal resources of eastern Kentucky may be considerably less than M. R. Campbell's estimate of 1929. The difference results from using more conservative methods in calcu-

lating resources, and from recent information showing that thick coal beds are absent in some areas Campbell included.

Through 1955, approximately 1700 million tons of coal had been mined in eastern Kentucky. Most production has been from Pike, Floyd, Letcher, Harlan, Perry, and Bell counties, where some of the thickest and best coal has already been mined. Continued exploration should be encouraged to outline new reserves needed to increase coal production. In many areas geologic mapping can provide the information but exploration by drilling and trenching will be necessary where the coal beds are not exposed.

GEOLOGY OF THE BELLTOWN FAULT, KENTUCKY

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This major east-west disturbance of central Kentucky was discovered by the writer about 3 miles southeast of Lebanon in south-central Marion County, in October 1925. It extends 45 miles, from Caney Creek of the Salt River to Bacon's Creek, a tributary of the Nolin River. It is a normal fault with downthrow on the south side; displacement ranges from 50 to 100 feet. In the vicinity of Badger it fans out into five separate faults with intervening elevated and depressed blocks. On the head of Brush Creek in northern Green County the course of the Belltown fault is broken by the sharply folded Brush Creek Dome. Surface rocks ranging upward from Richmond limestones and shales (Upper Ordovician) into Pottsville sandstones and conglomerates (Lower Pennsylvanian) crop out along the Belltown fault in Marion, Larue, Taylor, Green and Hart counties. This disturbance: (1) connects the Salt River, Kentucky River, and other well-known fault systems of central and eastern Kentucky with the Rough Creek faulting of western Kentucky; (2) completes the regional east-west pattern of faulting in Kentucky; (3) ties earth movements and structural features of the Ozarks in Missouri with the Chestnut Ridge disturbance in West Virginia and Pennsylvania.

REGIONAL GEOPHYSICAL DATA AND THEIR RELATION TO THE APPALACHIANS IN CENTRAL AND WESTERN VIRGINIA. PART I: REGIONAL AEROMAGNETIC SURVEYS

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Intrusive rocks of the Shenandoah Valley in Virginia form part of a dike swarm that extends northwestward from Triassic basins and the Piedmont, across the Blue Ridge and folded Appalachians, ending near the Appalachian structural front. Constituent dikes range in age from late Precambrian to Triassic and in composition from peridotite to nepheline syenite. The petrology changes along the swarm as the dikes transect the various structural provinces. Geophysical data, if considered with the dike swarm and other regional geologic features, indicate a major structure which lies transverse to the Appalachians.

Some aeromagnetic anomalies may be correlated with surface geology. The metavolcanic rocks of the Precambrian (?) formation that lie on the flanks of the Blue Ridge anticlinorium give rise to very strong, sharp, magnetic anomalies; smaller anomalies are associated with bodies of hornblende metagabbro. West of the Blue Ridge, small anomalies occur over the dikes, plugs, and sills. A magnetic anomaly that can be correlated with no known geologic feature apparently stems from a source at great depth beneath the Shenandoah Valley and may be caused by an intrusive mass—possibly the source body for one group of dikes.

SEDIMENTARY ANALYSIS OF TERRACE DEPOSITS IN PANHANDLE OF FLORIDA

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Sedimentary analysis of 40 samples from four previously recognized terrace surfaces in a portion of the panhandle of Florida indicates that sedimentary parameters are useful in distinguishing indi-

vidual terraces. Comparison of size-distribution data and heavy-mineral analyses suggests that three rather than four terraces are distinguishable in the area under study. A composite profile across the area offers supporting evidence for the presence of three rather than four terrace surfaces.

URANIUM AND THORIUM IN THE SOUTHEASTERN STATES

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Since 1944, geologic studies by Federal and State agencies and prospecting by mining companies and individuals have indicated occurrences of uranium and thorium in each of the physiographic provinces of the Southeast, but no uranium ore has been discovered.

The principal known occurrences are:

	Uranium	*Thorium*
Coastal Plain	Phosphate rock in Florida and South Carolina	Beach and stream placers from Virginia to Florida
Piedmont	Pegmatites	Stream placers in the Carolinas; pegmatites
Blue Ridge	Veins, especially in northwestern North Carolina; pegmatites	Pegmatites, stream placers
Ridge and Valley, Appalachian plateaus, Interior Low Plateau	Chattanooga Shale, especially in Highland Rim of Tennessee	Stream placers

The only production of uranium in the southeastern states is by-product recovery from Florida phosphate rock. Monazite was mined from North Carolina stream placers before 1917 and is now being recovered, with other heavy minerals, from sands in Florida and South Carolina.

Except for by-product recovery, the Southeast is unlikely to become an important source of radioactive minerals, but its low-grade reserves are very large. The Florida phosphate field contains an estimated half a million tons of uranium. Although the Chattanooga Shale contains several million tons of uranium, it is of no present economic importance because of the very low grade and difficulty of extraction. Some granites may also be noneconomic low-grade reserves.

Prospecting may yet lead to discovery of ore bodies, but "rainbow-chasing" should not be encouraged. Favorable areas for uranium prospecting include some areas of granitic rocks in the Blue Ridge, the mineralized parts of the Carolina slate belt, and the clastic sedimentary rocks of the Appalachian Plateaus.

IRON DEPOSITS OF THE CLIFTON FORGE AREA, VIRGINIA

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Between 1832 and 1923 the iron mines around Clifton Forge, Virginia, produced about 10,000,000 tons of ore. Most of the iron deposits are in an area about 25 miles long and 10 miles wide in parts of Alleghany, Botetourt, and Craig counties. The principal deposits are the Oriskany iron ores which are localized in the upper sandy member of the Licking Creek Limestone of early Devonian age. These deposits form tabular bodies in moderately dipping beds on the flanks of large folds. The ore bodies are overlain by a ferruginous sandstone breccia which is in turn overlain locally by residual masses of kaolinized Middle Devonian shale.

The iron ores, which consist of veins and nodules of massive and colloform goethite in sand and clay, are believed to be of supergene origin. The iron, originally in the form of pyrite in the overlying Millboro Shale of Middle Devonian age, was probably dissolved by slightly acid ground water and carried downward into the Licking Creek Limestone where the acid was neutralized. The iron was precipitated as goethite which partly replaced the limestone and partly filled solution cavities in it. Besides the structural and stratigraphic controls, favorable geochemical conditions and a long period of chemical weathering are necessary for the formation of such deposits. Most of the iron deposits and the associated kaolinite were probably formed during the Harrisburg erosion cycle, at

which time deposits of manganese, bauxite, and kaolinite were also formed in neighboring parts of Virginia.

BETTS QUARRY CASE, HARRISONBURG, VIRGINIA

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The occurrence of an unusual black limestone facies in the uppermost Beekmantown in the tightly folded rocks of the Betts Quarry near Harrisonburg, Virginia, has led workers to resort to major faulting to explain the apparent relationships. It can be demonstrated that this black fine-grained limestone conformably overlies Beekmantown dolomite and gives way upward to basal Middle Ordovician limestone. Previous interpretation of the structure of the tight but minor infold of the quarry area has been unduly complicated, because the black limestone is lithologically strikingly similar to limestone in the Athens (Edinburg) Formation above Middle Ordovician limestone. Although bedding-plane slippage and associated shear cleavage is prominent in places in the quarry, and minor adjustment faulting did occur locally, no major faulting took place.

The apparently local occurrence of this black-limestone facies may be genetically related to the abnormally thick section of high-calcium limestone in the lower part of the overlying Middle Ordovician limestone. Here the widespread unconformity between the Lower Ordovician Beekmantown and Middle Ordovician limestone is missing, and the exact position of the contact between these units is uncertain. Black limestone of the Betts Quarry type can be expected to occur elsewhere in the uppermost Beekmantown. Perhaps recognition of this black limestone facies in the uppermost Beekmantown may aid in interpreting other supposedly structurally complex areas elsewhere in the Shenandoah Valley.

MIDDLE ORDOVICIAN LIMESTONES OF THE JONES VALLEY ANTICLINE AND ITS NORTHERN EXTENSIONS IN NORTHERN ALABAMA

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On the eastern flank of Jones Valley, the Chickamauga Limestone (250 feet thick) may be divided into three units: I, II, and III in ascending order.

Unit I is a dense to fine-grained (⅛–½ mm), light-gray, medium-bedded (4–12 inches) limestone. Calcite eyes and shale partings are common. At the base of Foster Mountain this limestone is underlain by 6–8 feet of a light-gray shale alternating with thin beds of nodular limestone. Beneath this is 6–7 feet of a light-gray shale, which rests on limestone of Beekmantown age.

Unit II is a dark-gray to medium-gray, generally medium-grained (½–2 mm), thick-bedded (1–3 feet) to very thick-bedded (3 feet plus) limestone. Characteristically this unit has at least two thin beds (1–4 inches) of a coarse-grained (2–4 mm) limestone. Nodules of black chert are present.

Unit III is a thin- to medium-bedded, medium-gray limestone. Several thin beds of coarse-grained clastic limestones are present toward the bottom of this unit. A zone 1–5 feet thick of cross-bedded limestone is found in the middle of this unit. The upper 4 feet of unit III contains nodules of dark-green chert. At one locality a thin bed of crinoidal limestone is present.

The maximum thickness of the Chickamauga Limestone (635 feet) is found on Foster Mountain.

WATER-SUPPLY DEVELOPMENT AND TRENDS IN THE SOUTHEASTERN STATES

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The per capita use of water for industry, irrigation, and municipal needs in the United States has increased many fold during the past 50 years. The increased use reflects the spread of industrializa-

tion, the development of new industries, the rapidly rising standard of living, and the increase of population. In no part of the nation has this increase been more notable than in the Southeastern States. The growth of industry, already under way, was accelerated by the development of the Tennessee River and other large streams and was maintained by the heavy demands for ever higher production to meet war needs and later to support the rapidly expanding postwar economy.

Fortunately, the Southeastern States have a relatively high rainfall, a terrane that promotes favorable runoff factors, and many large areas of extremely productive ground-water reservoirs. The water supplies are adequate for all foreseeable needs, provided they are developed at the most favorable spots and in the most efficient ways. Although several trouble spots have appeared, State and Federal agencies are moving steadily toward acquiring the extensive knowledge of geology, hydrology, and topography of the region that will be required for sound and effective development of the water resources.

LATE CRETACEOUS EROSION SURFACE IN SOUTHWEST VIRGINIA

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A late Cretaceous or Early Tertiary erosion surface in southwestern Virginia is indicated by the presence of a lignite lens in colluvium overlying a belt of Shady dolomite at an elevation of 3150 feet on Brushy Mountain, Smyth County, Virginia. On discovery, specimens of the lignite were submitted to Dr. Elso S. Barghoorn of Harvard who established their age by botanical means. The surface on which the plant remains accumulated appears to have been a fairly low-lying erosional surface drained by northwestward-flowing streams.

Apparently many deposits of manganese, residual silica sand, and clay and gossans were formed during this time; for example, formation of the manganese-bearing clays appears to be related to long chemical weathering of colluvium and rocks overlying the Shady dolomite with subsequent engulfment of the resulting materials as the underlying Shady dolomite underwent chemical leaching. These deposits now occur in areas that appear to represent parts of the erosion surface that have experienced the least subsequent erosion and thus may be considered to be erosional remnants of the once more extensive erosion surface. Recognition of this erosion surface is of special significance to the understanding of many of the mineral deposits of the region. It is believed that deposits of manganese, silica sand, and clay, gossans on metallic sulphides, and possibly other materials in the area can be discovered more readily and worked more intelligently if the erosional history of the area is made a primary consideration.

NEW OUTLOOK FOR THE BITUMINOUS COAL INDUSTRY

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Bituminous coal represents the most important geologic resource of the Southeastern section and probably will retain that position for a long time. The erratic economic past of the bituminous coal industry is well known. It is characterized by periods of at least mild prosperity interspersed with equally frequent and lengthy periods of severe depression. In general the bituminous coal industry has suffered from surpluses of almost everything except a stable market for its product—too much coal, too many operating properties, too much capacity, and too many people depending upon the industry for their livelihood. It has been extremely vulnerable to the inroads of competitive fuels and appeared to be destined to be the first to feel the impact of nuclear fission as a source of thermal energy.

As late as the early part of 1954 the economic condition and prospects of the bituminous coal industry were unfavorable, and the common prediction for its future was pessimistic. Late in 1954 certain changes began to develop in the demand and markets for bituminous coal that appear to chart a future for the industry that is decidedly different from its past. Technical developments in production, processing, and utilization have established a price advantage for coal over its competitors

as an industrial fuel that points toward stable markets for coal at unprecedented tonnage levels in the immediate and long-range future. Export markets, particularly in Western Europe, which in the past have depended upon temporary fuel shortages in the consumption areas because of short-duration interruption of local production or unusual periodic demands, have stabilized; they represent permanent and growing outlets for American coal and appear certain to play an important role in the future of coal mining in this country. Confidence in the industry has been restored, and investment money has poured into new developments and plant expansions.

GEOLOGY OF THE SCOTTSVILLE BASIN, VIRGINIA*

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The Scottsville Basin is a downfaulted, erosional remnant of a Triassic alluvial apron. It is bounded on west, north, and east by normal fault zones, and the greatest displacement occurs along the west. Faulting occurred before, during, and after formation of Triassic rocks.

The alluvial apron is divided into three mappable units: older fanglomerate, volcanic rocks, and younger fanglomerate. The fanglomerates are heterogeneous, ill-sorted, immaturely weathered, lenticular clastics, typical of the post-orogenic piedmont facies. The volcanic rocks were extruded through the west fault zone and are: tholeiitic metadiabase feeder intrusives, tholeiitic metabasalt flows, metatuffs, and derived metaclastics. Locally, boulder conglomerate is cemented by diabase.

The sediments, derived from a western source area, were deposited as coalescing alluvial fans which indicate simultaneous tectonism and sedimentation. During sedimentation the apron was displaced relatively downward by movement along the west fault zone. This faulting hinged on an axis in the east fault zone where subordinate movement occurred. As faulting continued in the west zone, successively younger sediments were deposited. The original dip of the older sediments, and eventually of the younger sediments, was gradually changed to a west dip. Post-sedimentation faulting has steepened the westward dip.

An irregular zone of post-sedimentation, hydrothermal alteration follows the west fault zone and has altered the younger fanglomerate, volcanic rocks, and upper portion of the older fanglomerate to the green-schist facies.

Post-hydrothermal tholeiitic diabase dikes which formerly cut across all fault zones have been severed by late movement along the west fault zone.

RADIATION SURVEYS REVEAL SUBSURFACE FAULTS

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The gamma-ray survey is most useful in the location of faults and related structural conditions. It should be correlated with geological data wherever possible. A study of surface radiation patterns made with mobile ionization equipment shows the existence of distinct characteristics over faults. An increase in gamma activity above the fracture is generally a basic characteristic of the fault zone. These radiation-intensity increases have been attributed to the migration of radioactive gases through the fault fracture and to the increased deposition of radioactive minerals by ground-water movement through such a region. The decay products formed by the disintegration of thorium and uranium, which are contained in nearly all sedimentary rocks, migrate to the surface in the form of radon and thoron gases. Although these two gases do not emit gamma rays, two of their decay products, radon C and thoron C, are extremely rich sources of gamma radiation.

The major source of radiation detected is in the upper 6 feet of the earth. Since this material is normally leached out by water, there must be some replacement agency present to permit duplication of radiation patterns over a period of years. Although minor background variation will be present because of the random nature of radioactive disintegration, these patterns can be and have been duplicated. The writer's work has not confirmed decreases in radiation over oil reservoirs. Apparently

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radiation lows with the so-called "halos" exist only where an oil pool lies below high-density (and nonporous) anticlinal strata. High radiation-intensity patterns have been noted over numerous oil fields, especially where multiple horizons contain oil.

GRAVITY-ANOMALY PATTERNS IN VIRGINIA

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Regional gravity investigations in Virginia have shown that much of the Bouguer gravity-anomaly pattern must be attributed to crustal structural deformation rather than surficial or near-surface geologic features. Although corrections for isostatic compensation for variations in surface elevation yield residuals that are significantly smaller, those isostatic anomalies also appear to be influenced in large measure by crustal structure. By using empirical methods, however, residuals can be obtained that show a definite relationship to surficial geologic features. Residual gravity maps have been prepared for the area in order to facilitate correlation studies with known geologic features and magnetic measurements, so that the complex geology of the area can be better understood.

DISTINGUISHING FEATURES OF CHESTER AND LOWER PENNSYLVANIAN ROCKS IN THE ILLINOIS BASIN

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The pre-Pennsylvanian unconformity is hard to recognize at many points in the Illinois basin. A common error is to place it at the top of the highest Chester limestone present, for Chester sandstones and shales resemble lower Pennsylvanian strata.

Of the traditional criteria for distinguishing Pennsylvanian from Chester, the presence of coarse sand, quartzite pebbles, and abundant mica flakes is excellent. Criteria utilizing the presence of locally derived materials such as siderite, limonite, coal, carbonaceous fragments, and black color in the Pennsylvanian, or limestone, calcite, dolomite, oölites, fossil fragments, and red or green colors in the Chester are less reliable.

Greater angularity of Pennsylvanian quartz sand grains as originally deposited may be masked by crystal growth, but the ratio of angular to rounded tourmaline grains is sharply discriminatory. Differences in other petrographic ratios reflecting changes in the sediments supplied to the basin are generally so slight that their ranges in Chester and Pennsylvanian rocks are apt to overlap.

Clay-mineral data are not always conclusive, though in general kaolinite is more abundant in the Pennsylvanian, and mixed-lattice clay minerals in the Chester. Chester limestones, many Chester shales, and some Pennsylvanian shales are identifiable on electric logs, but in general the sandstones must be distinguished by their stratigraphic relations rather than by their electrical characteristics. Some Pennsylvanian black shales are more radioactive than any Chester beds.

SEWER OR WASTE-DISPOSAL USE OF THE OHIO RIVER

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Because rivers provide the natural drainage lines for their watersheds, one of the logical and vita multiple uses of a river is to act as an open sewer. The Ohio River functioned adequately as a sewer until after 1900.

Before waste loads became too heavy and accumulation of pollution deposits too deep, the Ohio River was able to dilute and partially purify the untreated domestic wastes and in later years to "flush out" most of the wastes. However, by the 1920's the annual untreated city sewage and industrial waste loads were so great that dilution was no longer a possible solution to pollution; natural means of purification by flowing water between sewer outlets became impossible, and sewage solids started to collect along the banks.

During the same decades man was rapidly increasing the volume and variety of wastes; he was impairing the river's ability to purify them.

Man has always used the Ohio River in a variety of ways. But pollution of the river became so foul that other uses were impaired. Recreation and wildlife uses declined. Cities were finding it difficult to treat adequately the water for human drinking purposes.

In 1948, the Ohio River Valley Water Sanitation Compact was created so that eight States might faithfully co-operate "in the control of future pollution and abatement of existing pollution" in the Ohio River watershed. Progress to date has been encouraging, but much remains to be done. Water Sanitation Compact is definitely an experiment in regional conservation.

INTERGLACIAL AND LATE-GLACIAL VEGETATION OF THE NORTH-CENTRAL UNITED STATES

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The widely used concept of orderly withdrawal and return of climatically zoned plant communities in response to advance and retreat of Pleistocene ice sheets in North America is largely assumption. Similarly, the commonly held idea that tundra vegetation bordered most, if not all, margins of continental ice sheets is even more difficult to support with evidence. Both concepts are probably misleading our further thinking.

The fossil record of vegetation in front of advancing ice borders is meager but may be interpreted as indicating indistinct zonation and confusion of communities as we know them in modern vegetation. Taigalike patterns of boreal forest elements, including patches of treeless vegetation, have been repeatedly demonstrated for areas along stable and retreating ice borders. Periglacial zonation of vegetation, however, was apparently related more to relative aggressiveness of pioneer species than to selection of communities by climatic control.

The treeless communities along ice borders may well have been allied to tundra physiognomically and through presence of some species in common; but this treeless vegetation was not necessarily genetically related to tundra—i.e., it was not derived from high-latitude tundra communities or populations. Certain evidence can be interpreted to mean that, during changing conditions of the Pleistocene, some plant communities were brought into existence and persisted for only a relatively short time. On the other hand, repeated finds of similar combinations of species in fossil assemblages argue for probable continuous existence of other communities since at least early Pleistocene time.

PROBLEMS ALONG THE MARGIN OF THE WISCONSIN DRIFT IN PUTNAM COUNTY, WEST-CENTRAL INDIANA

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The outer margin of the Wisconsin drift divides Putnam County into two natural areas. End moraines are subdued to absent, but land forms differ sharply between Wisconsin drift plains to the north and Illinoian eroded uplands to the south. The cultural break is as sharp as the physical break. Columns, maps, and charts are presented to summarize field observations. Problems include compositions of the tills, direction of ice flow, details of the pre-Pleistocene surface, ground-water difficulties, and the age of buried fossil flora and fauna.

PLEISTOCENE CLIMATIC CHANGE RECORDED BY ICE-WEDGE POLYGON CASTS OF CARY AGE AT RIVER FALLS, WISCONSIN*

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In a borrow pit at the junction of county roads M and MM, River Falls, Wisconsin, is a well-developed network of ice-wedge polygon casts. Fillings consist of clean, tan, fine- to medium-grained sand in marked contrast in color and texture to enclosing poorly sorted, dirty, sandy-gravelly kame deposits. The south and east sides of the pit, about 100 m long, reveal 45 ice-wedge casts. Wedges in primary polygons 5–10 m in diameter are 0.4–1.0 m wide and 1.0–2.0 m high; wedges in secondary polygons 2–4 m in diameter are 0.1–0.4 m wide and 0.3–1.7 m high. Upturned bedding from pressure effects during growth of ice in the wedges is plainly visible adjacent to many casts.

* Field studies were aided financially by the Wisconsin Alumni Research Foundation.

The kame, considered to be Tazewell in age, lies 4 miles beyond the southern margin of Cary ice. By extrapolating from data on ice-wedge growth in northern Alaska, the wedges required 1000-2000 years in early Cary time to reach their present size. They reflect conditions today found only in zones of continuous permafrost in northern Alaska and Canada; this involves a change in mean annual temperature from 44° F. today at River Falls to 15°–20° F. in early Cary time. The wedges were destroyed when late Cary outwash dammed Kinnickinnic River Valley, producing a very temporary lake over the site. Slow thaw and concurrent filling subaqueously enabled the unique casts to form. Still later in Cary time, after the lake was drained, mass wasting removed the sediments over the kame and truncated many wedges.

LATE PENNSYLVANIAN FACIES OF NORTH-CENTRAL OKLAHOMA

Carl C. Branson
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Virgilian rocks of north-central Oklahoma lack the cyclic characteristics of their correlatives in Kansas. Coal beds occur only beneath the top member of the Pawhuska limestone, beneath the Elmont limestone, and in association with the Grayhorse limestone. Continuity through as much as 50 miles is exhibited by the Lecompton, Turkey Run, Bird Creek, Wakarusa, Reading, Elmont, Grayhorse, and Brownville limestones. The early Virgilian rocks are predominantly sandstone. These and the higher Virgilian rocks grade into red beds southward. At N. Lat. 35° 30′, the Virgil Series consists of the Vamossa formation, a red claystone and pink sandstone unit; Pawhuska formation with thin Lecompton and Turkey Run limestone members; Severy shale; thin Bird Creek limestone; Hallett formation; Wakarusa limestone; Auburn shale; Emporia limestone, with Reading and Elmont members; Gano shale; and Brownville red dolomite. These 10 formational units contrast with the 21 formational units of present Kansas classification and the 37 recognized before 1956.

MISSISSIPPIAN SMALLER FORAMINIFERA OF EAST-CENTRAL UNITED STATES

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Emphasis is placed upon Lower Mississippian smaller Foraminifera that occur in Indiana, Kentucky, Ohio, and Missouri in beds previously thought to be unfossiliferous or to bear only megafossils. Related work demonstrates the presence of Foraminifera in the Greenbrier limestone (Chesterian part) of West Virginia and the Chesterian Paint Creek and Kinkaid limestones (shales) of western Kentucky. These Mississippian smaller Foraminifera are similar to Pennsylvanian Foraminifera of Texas and Ohio. Age determinations and correlations of Mississippian deposits in east-central United States may be based on smaller Foraminifera.

In Ohio a fauna dominated by *Ammodiscus* indicates a Mississippian (Kinderhookian) age for the Bedford shale. The Osagian Cuyahoga formation of Ohio and the Osagian New Providence formation of Kentucky contain a *Thuramminoides-Hyperammina* fauna which sets these beds apart from the Bedford shale. Meramecian deposits may be distinguished in east-central United States by species of the well-known *Endothyra-Plectogyra* foraminiferal suites. Adequate investigations have not been undertaken to determine possible occurrences and usefulness of smaller Foraminifera in the Meramecian. Smaller Foraminifera should prove useful in correlation of the Chesterian deposits of western Kentucky and southern Illinois.

Ecologically the Mississippian smaller Foraminifera, overwhelmingly arenaceous, were mostly confined to silty, calcareous to highly argillaceous shales and were unsuited for life in high-calcium carbonate waters; however, the *Endothyra-Plectogyra* suite flourished in high-calcium carbonate waters and occupied the shoal and/or reef environments which were later inhabited by miliolid Foraminifera of the Early Cretaceous and early Tertiary.

ECONOMY AND LAND-USE PATTERNS IN THE SIWA OASIS, LIBYAN DESERT

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Siwa, an Oasis in the Libyan Desert, politically a part of Egypt, is located about 350 miles west-southwest of Cairo. In the somewhat remote and isolated area 30 miles in length and 5–6 miles in width live about 4000 people of Libyan (Berber) stock who in the long occupation of the region have evolved a very interesting and workable connection with the land (and water).

A metalled road now extends for more than a third of the distance from Marsa Matrouh on the Mediterranean to Siwa. For the rest of the distance no road exists. However, a telegraph line extends the entire distance from Marsa Matrouh to the Oasis and hence acts as a guide to those who otherwise might stray far from the most direct route.

The "gardens," dominated by date palms and olive trees, are distributed in a unique pattern on the floor of the Oasis which lies 72 feet below the level of the Mediterranean. Two hundred or more springs or wells furnish irrigation water in varying amounts.

The spring openings are generally circular, 30–60 feet in diameter, and 15–30 feet deep. Water from the springs flows directly either to the gardens or to storage reservoirs. From the reservoirs water is allowed to flow when needed. All the drainage canals are interconnected, and the drainage waters finally reach a huge salt lake called the Saline, a unique feature in a very dry desert.

Two problems face the Siwans in land utilization—the decreasing amount of water and increasing salinity of the soils. Some land has already been abandoned. On the other hand, some land that has never been cultivated may in the future be used for agriculture.

Two villages, Siwa Village and Aghourmi, are market towns.

GLACIAL DEPOSITS OF CENTRAL AND WESTERN OHIO

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Ohio Geological Survey, Columbus, Ohio

Pre-Illinoian, Illinoian, and Wisconsin glacial stages are recognized in Ohio. Evidence for pre-Illinoian glaciation occurs as (1) till, weathered deeper than near-by Illinoian till, in southwestern Ohio; (2) deposits accumulated in the preglacial, ice-dammed Teays River valley; and (3) other drainage changes demanding the presence of a pre-Illinoian glacier. The till in southwestern Ohio is called "Kansan(?)"; ponding of the Teays River, by the first ice to invade Ohio, may have been by the same or by an earlier glacier.

Illinoian ground moraine, with occasional remnants of end moraine, forms a narrow belt outside the Wisconsin boundary. Illinoian kames are present locally; Illinoian terraces occur along most of the major south-flowing streams.

Wisconsin drift covers most of glaciated Ohio, forming a succession of end moraines separated by broad areas of ground moraine. Kames stand singly or in large kame fields; several levels of terrace occur.

"Early" Wisconsin (as defined by Goldthwait) drift has been recognized forming end moraine in Highland County and terraces in the Hocking River valley. In both areas, age assignment is based on deep, strongly weathered soil profiles and significant relationships of these deposits to other glacial features.

The "late" Wisconsin advance is pinpointed by a series of radiocarbon datings, from 24,600 ± 800 years (W-71) at Cleveland to 18,000 ± 400 years ago (W-331) at Chillicothe. The earliest postglacial date (Arkona) is 13,600 ± 500 years (W-33). Thus, this "late" Wisconsin must include Farmdale, Iowan, Tazewell, and Cary time as defined in Illinois. Regional differences in soil profiles within this area may relate to these substages.

PENNSYLVANIAN HISTORY OF THE CRINER HILLS AREA, OKLAHOMA

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The Criner Hills, in southern Oklahoma, a few miles south of Ardmore, occupy about 32 square miles. Within this small area evidence of two periods of movement during the Pennsylvanian period are plainly preserved.

The first period of movement, the Criner-Wichita orogeny in early Morrow time, resulted in the folding, faulting, and truncation of the pre-Pennsylvanian strata. The second period of movement, the Arbuckle orogeny late in the Pennsylvanian period, superimposed folded Pennsylvanian sediments upon the earlier structures. Structural trends of both orogenic periods are observable in the Criner Hills.

GEOMORPHOLOGY OF THE SHAWANGUNK RANGE OF ULSTER AND SULLIVAN COUNTIES, NEW YORK

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Morphology of the Shawangunk Range of Ulster and Sullivan counties, southeastern New York, is directly related to and controlled by the lithology, thickness, and structure of the Shawangunk conglomerate; geomorphic process and stage are comparatively less significant in producing its present landforms.

The presence and thickness of the Shawangunk conglomerate seem to determine the type of yielding to deformation. Southwest of Rosendale, where the formation is present in the section, deformation has been dominantly by folding. Wider-radius folds are more common southwest of High Falls where the thickness of the competent Shawangunk conglomerate is greater. The relationship between the morphology of the Shawangunk Range and the structure of the Shawangunk conglomerate is manifested in the following ways:

(1) The axis of the Shawangunk Range trends approximately parallel to a structural salient and recess in the Kerhonkson and Gardiner quadrangles.

(2) The stripped rock surfaces of the northwest flank of the Shawangunk Mountains coincide with the dip slope of a major anticline.

(3) Major valleys in the Mohonk Lake quadrangle coincide with the trend of at least five synclinal axes. Major ridges of the Mohonk Lake quadrangle coincide with the crests of northeast-plunging anticlines and disappear to the northeast coincident with the direction of regional plunge and regional thinning of the conglomerate.

(4) Ridge altitude and width generally coincide with the amount and variation in dip, suggesting that present summit levels do not represent remnants of an old erosion surface.

(5) Major drainage is adjusted to structure.

TYPES OF PENNSYLVANIAN CHANNEL SANDSTONES IN INDIANA*

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Four main types of channel sandstones are recognized in a part of the middle Pennsylvanian of Indiana: (1) exhibits a dendritic pattern whose branches coalesce and contain sandstone that thickens downdip; (2) exhibits a dendritic pattern but has a uniform thickness downdip; (3) trends normal to the strike; and (4) lies parallel to the strike; types (3) and (4) are sinuous in plan.

The sandstone in the main channel of type (1) is sinuous and lens-shaped, and its base is convex downward. In one area it trends southwestward 6 miles, is 2000 feet wide at the top, and is 90 feet

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thick. This sandstone is light brown, thick-bedded, locally cross-bedded to the southwest, and fine-to medium-grained.

Type (2) in one area cuts out and intertongues with shales and coals. This sandstone trends southwestward 4 miles, is 2000 feet wide at the top, and is 40 feet thick.

A study of one sandstone of type (3) shows that it trends southwestward, is 7 miles long, and is 2600 feet wide at the top; it cuts out and contains fragments of a commercial coal.

Type (4) in one area exhibits a northwestward trend and is 3 miles long, 5000 feet wide, and 60 feet thick. The sandstone is light brown, thick-bedded, and locally cross-bedded to the northwest; it is medium- to coarse-grained and contains plant fossils most of whose long axes trend northwestward.

GENUS *AGASSIZOCRINUS* AS A STRATIGRAPHIC MARKER

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The presence of *Agassizocrinus* in the Chester (Upper Mississippian) has been noted frequently in the literature although the exact formational limits of certain species have been very indefinite. Recent studies of *Agassizocrinus* indicate its stratigraphic usefulness, despite the fact that only the fused infrabasal plates in the form of a conical or semiovoid cup must be relied upon. The shape of the cup is usually sufficient to identify the species, and the presence of several new species, particularly in the Upper Chester, is noted.

The relationship of *Anartiocrinus* and *Paragassizocrinus* to *Agassizocrinus* is discussed and a structural comparison is presented.

ARENACEOUS FORAMINIFERA FROM THE ROCKFORD LIMESTONE OF NORTHERN INDIANA

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Several thousand arenaceous Foraminifera, representatives of a prolific fauna, have been obtained from insoluble residues of Mississippian Kinderhook Rockford limestone collected from two localities in Jasper and Benton counties, Indiana. More than 25 species among 15 genera in the families Astrorhizidae, Saccamminidae, Hyperamminidae, Reophacidae, Ammodiscidae, and Lituolidae are identified.

Distribution of forms is divided between those with affinities to older Silurian and Devonian faunas and others, in greater number, with affinities to the younger Pennsylvanian described arenaceous Foraminifera. The assemblage is a transitional one of many overlapping long-ranged species. More phylogenetic studies from ever-increasing faunal documentation of Paleozoic arenaceous Foraminifera must be made before one can determine the index value of the individual species.

PENNSYLVANIAN CONGLOMERATES AND TECTONIC HISTORY OF THE ARBUCKLE MOUNTAIN REGION, OKLAHOMA

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The Arbuckle Mountain region of south-central Oklahoma is made up of Cambrian through Pennsylvanian rocks 29,000 feet thick that were folded and faulted during several orogenic episodes within Middle and Late Pennsylvanian time. The region is differentiated into (1) a southern basin province of thick sediments that are strongly folded, partly overturned, and locally thrust-faulted, and (2) a northern shelf province of much thinner sediments that are moderately folded and block-faulted.

Structural evolution, as deduced from the age and distribution of three mountain-derived conglomerate sequences, began early in mid-Pennsylvanian Desmoinesian time with broad epeirogenetic

uplift of the northern shelf area. It continued to rise slowly and to contribute marginal conglomerates until late Pennsylvanian Virgil time, yet total structural relief was only 4000 feet.

Little affected by this early deformation, the basin segment collapsed with its geosynclinal sediment thicknesses during two strong orogenic pulses of middle and late Virgilian time, resulting in structural relief of at least 16,000 feet. Widely known in the Midcontinent region as the Arbuckle orogeny, it was short-lived but severe, producing two major anticlinal folds each of which covers more than 150 square miles, uncovering for the first time an extensive area of Precambrian granites, and yielding two limestone boulder conglomerates having a combined thickness of 3500 feet.

WISCONSIN GLACIATION OF THE INDIANAPOLIS, INDIANA, AREA*

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Studies of drift stratigraphy in stream and road cuts throughout Marion County, Indiana, indicate that the Indianapolis area was glaciated by two advances of the East White sublobe of the Ontario-Erie lobe during the Wisconsin age. A basal Wisconsin till is correlated with the "Shelbyville" (outermost Wisconsin) drift but may be of Iowan age. Till above the basal unit is correlated with "Champaign" drift and is of Tazewell age. A discontinuous and relatively thin top till unit is representative of short readvances of the "Champaign" ice during general recession.

Preconsolidation-pressure data from silts that were overridden by the "Champaign" advance permit the estimate that more than 90 cubic miles of ice covered the county during "Champaign" time. An arcuate pattern of ice-marginal streams resulted from melting of this glacier lobe. These streams trenched till and outwash to depths of as much as 100 feet.

Samples of the till units were taken from sections near the four corners of Marion County for fraction analyses (mineralogy versus size). Mineralogy of the silt-clay till matrices is remarkably uniform. In order of decreasing mineral abundance quartz, calcite, dolomite, illite, and chlorite constitute the coarse fractions of the matrix, whereas illite, chlorite, kaolinite, quartz, and calcite constitute the finer fractions. The tills also show remarkable textural homogeneity. On a triangular diagram whose corners equal 100 per cent sand, silt, and clay, the till samples plot within a circle of 8 per cent radius whose center is at 43 per cent sand and 38 per cent silt.

MECHANIZATION OF BRITISH AGRICULTURE

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If one accepts the common, but only partially correct, assumption that farm mechanization refers simply to dependence upon tractor rather than upon horse power, British agriculture is as highly mechanized as any in the world. Yet there were so few tractors in Britain before the Second World War that the excellent British Agricultural Census did not even bother to enumerate them until 1942. Between 1942 and 1954 the number of farm tractors increased from 114,425 to 378,115 (330 per cent), while the number of farm horses was falling from 584,563 to 183,538 (31 per cent). This paper reports the present distribution of various indices of mechanization in Britain, analyzes the variations in degree of mechanization from county to county, and attempts to explain these variations as they are related to other significant phenomena.

DESMOINESIAN BRACHIOPODA AND MOLLUSCA FROM SOUTHWEST MISSOURI

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Fifty species and varieties distributed among 24 genera of brachiopods, 35 species contained in 25 genera of pelecypods, 10 species representing 10 genera of cephalopods, and 60 species distributed

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among 34 genera of gastropods were collected and are described from the lower portion of the Cabaniss subgroup, the upper portion of the Krebs subgroup, and from some pre-Desmoinesian deposits. Two new genera of brachiopods, eight new species and varieties of brachiopods, and eight new species of gastropods are here recognized for the first time. Faunal similarities can be seen in strata of equivalent age in Kansas, Missouri, Iowa, Illinois, Indiana, and Ohio. A significant faunal break is shown to be present in southwestern Missouri across the Krebs-Cabaniss boundary.

Deposits of Pennsylvanian age, present in solution depressions formed in the Jefferson City formation, are pre-Desmoinisian in age. Faunas from these deposits show some relationship to those of Atokan age. The fossiliferous strata in this portion of the section are shown to have been formed in a shallow-water, relatively near-shore, partially restricted, marine environment.

GEOLOGY AND PETROLOGY OF THE ANVIL ROCK SANDSTONE OF THE EASTERN INTERIOR BASIN

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The morphology and petrology of the Anvil Rock sandstone, which occurs at the base of the McLeansboro Group (Upper Pennsylvanian) in the Illinois basin, were studied to obtain a better understanding of the nature of channel sandstones and their importance in the exploration and exploitation of No. 6 coal.

The area studied includes most of the southern and western portions of the basin in Illinois and adjacent parts of Kentucky and Indiana. The Anvil Rock sandstone is widely developed throughout the deeper part of the basin and locally fills channels eroded in the underlying strata, replacing the Herrin (No. 6) coal in parts of some of these channels.

The widespread sheet phase of sandstone deposition is confined to the deeper part of the basin and does not occur in the western shelf area of Illinois. The distribution of the prominent erosion channels, however, does not appear to be related to differential subsidence because channel development is prominent in both shelf and deeper-basin areas.

The erosional channels seem to be of subaerial origin and to be filled dominantly with fluvial sandstone, siltstone, and shale. Subsurface channel pattern and measurements of surface cross-bedding indicate that the drainage was generally south-southwestward.

MISSISSIPPIAN STRATIGRAPHY AND TECTONICS OF THE OKLAHOMA OZARK AREA

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Rocks exposed in the Oklahoma Ozark area range in age from Precambrian to Middle Pennsylvanian. Early Paleozoic units are beveled by unconformity and are overlapped northward by the Chattanooga black shale (Late Devonian and Early Mississippian).

Post-Chattanooga beds include the St. Joe group (Compton, Northview, and Pierson) of Kinderhookian and Early Osagean age, Reeds Spring and Keokuk formations (Osagean), Moorefield formation (Meramecian), Hindsville, Fayetteville, and Pitkin formations (Chesterian). Osagean units disappear southward by truncation and are overlapped northward by the Moorefield. The latter is beveled northward by unconformity and overlapped by the Hindsville which lies on Osagean cherts in northern exposures. Overlying Fayetteville and Pitkin are truncated northward by pre-Pennsylvanian erosion and are succeeded by Hale, Bloyd, and Atoka formations (Pennsylvanian).

Northeastern Oklahoma lies on the southwestern end of the Ozark Dome. Formations strike in an arcuate pattern and dip gently away from the uplift. Regional dip is interrupted by northeast-trending faults and minor folds which roughly parallel the Ozark axis.

Structural development in northeastern Oklahoma is closely associated with that of the Ozark geanticline which underwent successive emergences, submergences, and tiltings during the Paleozoic. Major deformation occurred in Middle Pennsylvanian (Desmoinesian) time. Folds and faults are post-Boggy and pre-Tiawah (Senora) in age. Parallelism of structures with those in the Arkansas Valley syncline suggest genetic relations. Deformation is largely tensional, resulting from stretching of rock layers across the end of the positive Ozark area following orogenic movement in the Ouachita Mountains and subsequent adjustment in the McAlester Basin area.

POSTGLACIAL VEGETATION OF THE NORTH-CENTRAL UNITED STATES

Theodor Just
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The dramatic changes in climate and physiography following the retreat of the last glaciers are reflected in the record of forest succession as gleaned from pollen studies made chiefly in the Great Lakes area. Fairly rapid deglaciation began about 8500 B. C. while spruce-fir forests still dominated (Valders Retreat). Soon the pine came in, and spruce-pine forests took over (about 7000 B. C.). At the time of the Terminal Glacial (Cochrane, 6000 B. C.) pine was the dominant forest tree, whereas spruce-fir forests had migrated north. During the following 3000 years, while the climate was warmer and drier, pine forests were dominant. Then broad-leaved trees (oaks) made their appearance. First came an oak stage that extended until about 1000 B. C. It was followed, during the next 500 years, by an oak-hickory stage. The period from 7000 B. C. to 600 B.C. is now known as the hypsithermal interval, rather than by its former but less suitable designations (postglacial climatic optimum, thermal maximum), and as such has been correlated with corresponding stages in the European sequence and postglacial chronology. The various radiocarbon dates based on different sites and carried out in different laboratories have not yet been completely aligned but show considerable agreement with other sources of evidence.

Events during Late Glacial and postglacial times apparently had a more far-reaching effect on present-day distribution patterns of plants and animals than did those of the various Glacial and Interglacial periods. These pronounced postglacial changes in climate and physiography definitely affected the mode of life of various paleo-Indian groups living in this region.

PENNSYLVANIAN LIMESTONE TEXTURES IN SOUTHWESTERN ILLINOIS*

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Thin but persistent fossiliferous limestones at 11 different stratigraphic positions outcrop in St. Clair, Randolph, Perry, and Jackson counties, southwestern Illinois, as follows, listed in descending order: Trivoli limestone; Cutler limestone; Galum limestone; Bankston Fork limestone; Jamestown limestone; Jamestown "bottom rock"; Herrin limestone; St. David limestone; Oak Grove limestone; Seahorne limestone; and Curlew limestone. Most of them occur as cap rocks of coal beds in cyclic successions, but the Galum, Bankston Fork, and Jamestown "bottom rock" occupy positions of underclay limestones. Thin-section studies of samples of these limestones show that each has unique textural and faunal characteristics. They vary from coquina of well-preserved or broken shells to dense lithographic limestone. The Galum has thin-shelled fresh-water forms. The thickest limestone, the Cutler, has an abundance of fragments of calcareous algae. The Curlew, St. David, Herrin, Bankston Fork, and Cutler contain fusulinids. The St. David is finest-grained of all the beds and is virtually lithographic. The Bankston Fork is the most dolomitic bed. Comparison of textures of the same limestones in St. Clair County to the northwest and Perry and Jackson counties to the southeast indicates that the shore line of the seas in which the limestones formed generally lay to the west or northwest. Commonly the lower part of the limestone shows evidence of deposition in shallower water than the upper part.

* Presented with the permission of the Chief, Illinois State Geological Survey

This method of study when projected regionally for a single limestone will permit a clearer picture of depths of water, muddiness of the sea, and possibly varying temperatures or degrees of salinity.

PRE-WISCONSIN PEAT IN MILLBURY, MASSACHUSETTS

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During construction on the Massachusetts Toll Road in Millbury, in 1956, a cut 65 feet deep through Wisconsin till exposed a highly compressed peat bed, 4 feet thick. This deposit, which is unique in the records of central New England, is located on the east side of the Blackstone River Valley across which the ice sheet moved southeast. The till forms an immense drumlinoidal-shaped hill in the lee of ledges of gneiss, and the highway section is a typical example of "crag and tail". Borings to bedrock showed up to 12 feet of fine silt, much like loess, under the peat, but no other glacial deposits. Pollen analysis by E. S. Barghoorn identified about 30 species representing present plant types. Oak is the most abundant tree pollen; pine is quite low, and hickory is abundant. Sweet gum is sparse, but its presence is interesting since the tree reaches its northern limit today in southwestern Connecticut. A warmer climate than the present is suggested. Borings through the underlying silt encounter smooth bedrock which may indicate an abandoned high-level channel of Blackstone River into which westerly winds blew silt until swamp deposits completed the filling. The peat is pre-Wisconsin and may be Pliocene. Only one glaciation, the Wisconsin, is recorded, as elsewhere in New England.

TRENCH DIVERSIONS AND SALTON BASINS

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A stream entering one side of a topographic trench, and building a fan there, may be diverted on the fan to one or the other end of the trench. "Trench diversion" takes place on rivers with unstable channels at the beginning of a new cycle, and it may account for the courses of some rivers that now have deeply entrenched valleys. Examples of trench diversion have sometimes been confused with stream piracy, but piracy involves an interaction of two streams, while trench diversion is accomplished by one stream only. Some of the most remarkable trench diversions take place on continental divides; the Casiquiare Canal on the Orinoco is a possible example.

If a trench has one closed end, diversions into it may be trapped, like that into the Salton basin on the Lower Colorado River. "Salton basins" are formed on rivers that are at times diverted into closed depressions. They are most common early in the stream cycle or they may result from crustal warping. They are commonly found on rivers that were born on emerging sea floors in late-Glacial time, such as the rivers of the State of Maine.

RELATIONSHIPS OF THE WAYNESBURG, HOCKINGPORT, AND ANTIQUITY SANDSTONES OF THE DUNKARD BASIN

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The Waynesburg sandstone, of the lower part of the Dunkard series, has for more than 65 years been considered to be a more or less continuous deposit extending from southwestern Pennsylvania over most of the Dunkard Basin. Two relatively local sandstones, the Hockingport and the Antiquity, of the southwestern part of the basin have previously been considered parts of the Waynesburg sandstone. In the opinion of the writers these sandstones should not be correlated with the Waynesburg.

The true Waynesburg sandstone was deposited in the near-shore area of a shallow body of water. The Hockingport and Antiquity sandstones are the result of fluvial deposition. The Waynesburg, Hockingport, and Antiquity sandstones are similar in composition. However, the texture, primary structures, and nature of related deposits of the Waynesburg differ markedly from the other two sandstones.

The Dunkard Series has been considered Permian in age on the basis of its fossil flora, but the age of this flora has been questioned. The existence of a regional unconformity is not indicated by the structure, lithology, or fossil fauna of the rocks of the Dunkard Series nor by the strata of the underlying Monongahela Series; therefore these sandstones are not necessarily basal sandstones separating Permian from Pennsylvanian.

GLACIAL DEPOSITS: A MAJOR SOURCE OF GROUND WATER IN THE CENTRAL UNITED STATES*

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Alluvial sand and gravel deposited in drainageways that were directly associated with the continental ice sheet in northern United States and the Lower Mississippi Valley form some of the most widespread and valuable aquifers of Pleistocene age. They occur chiefly in existing or buried valleys and as scattered lenses in the glacial drift.

Specific examples are given of the distribution, nature, and yield of the glacial aquifers from areas in the central United States, and comparisons are made with Pleistocene aquifers in other regions.

Over a considerable part of the region glacial aquifers are the sole source of usable ground water and are an important supplementary source in areas where other aquifers provide the main supply. Water from sand and gravel is especially adaptable for use because it is easily available, constantly cool, and relatively constant in quality.

Major uses of water from the sand and gravel deposits in the north-central States are industrial, municipal, and domestic, whereas the chief use in the Lower Mississippi Valley is irrigation. Withdrawal is localized along ancient or existing drainageways where they contain sand and gravel. Only minor quantities for small domestic, municipal, and industrial supplies are taken from the scattered lenses in the glacial drift. Thus the geographic pattern of major irrigated areas, industrial concentration, and municipalities is influenced by the distribution of glacial aquifers.

GLACIAL GEOLOGY OF WESTERN AND CENTRAL NEW YORK

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Western and central New York were glaciated during one or more pre-Wisconsin ages, during a possible pre-Farmdale but post-Sangamon interval, and during multiple Wisconsin fluctuations. The Salamanca re-entrant, a small area south of the Allegheny River, escaped glaciation.

Pre-Wisconsin glaciation is indicated by deeply incised meltwater channels plugged with early Wisconsin marginal deposits, by high terraces in the Allegheny and Susquehanna valleys, and a buried soil profile near Fonda. Drift-filled preglacial and interglacial gorges are deeper and wider than their postglacial counterparts. On the basis of stratigraphic sections in three such gorges a possible pre-Farmdale but post-Sangamon glaciation is inferred. In each of the three sections peat underlying the uppermost till has been dated at more than 34,000 years before the present, yet none of the sections contain evidence of an erosion or weathering interval representative of the Sangamon.

Terminal Wisconsin deposits west of the Salamanca re-entrant have been traced continuously from Ohio across Pennsylvania and are of Early Cary age on the basis of initial radiocarbon dating. A succession of Late Cary moraines comprising the Lake Escarpment system of Leverett and, in part, the Valley Heads moraines of Fairchild are cut by shore lines of proglacial Lake Whittlesey in the

* Publication authorized by the Illinois State Geological Survey

Erie basin. The Hamburg moraine is believed to have imponded Lake Warren, and with subsequent ice-marginal positions is therefore referred to the Valders interval.

PENNSYLVANIAN ROCKS AND BASAL UNCONFORMITY IN WAYNE COUNTY, OHIO

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Pennsylvanian rocks of Wayne County, central northeastern Ohio, range from the Sharon conglomerate of Pottsville (Lee) Series up to shales and sandstones overlying the Middle Kittanning coal (Allegheny Series). They cover an area of 130 square miles in the northern Applachian basin. In order of relative abundance, the rocks consist of sandstones, shale, clay, coal, and limestone and show maximum thickness of 420 feet.

An unconformity with maximum relief of 270 feet separates Pennsylvanian from Mississippian (Osagean Series) rocks. Slump and differential-compaction phenomena are common at the unconformable contact on flanks of Mississippian "hills." A contour map drawn on the top of the Mississippian surface represents the first large-scale attempt to show the unconformable surface in the State. Future regional studies will be necessary to evaluate properly tentative conclusions made concerning (1) the apparent dendritic drainage pattern, (2) the southeasterly direction of drainage on the unconformable surface, and (3) the amount of structural influence, if any, of the older rocks on the configuration of this surface.

Pennsylvanian rocks of the county are readily subdivided into *cyclothems*. Pottsville rocks contain eleven coals, twelve underclays, two marine limestones and at least one iron ore and one conglomerate. Allegheny rocks contain three coals, two underclays and one marine limestone. Lateral limitations of all rock units were found, due to either non-deposition, lateral gradation or channeling. Deposition of rocks up to Quakertown coal was erratic because of the presence of Mississippian residual "hills"; subsequent deposition was more blanket-like in character.

STRATIGRAPHY OF THE RENAULT LIMESTONE AND "BASIN AUX VASES" IN INDIANA SUBSURFACE*

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Correlation of closely spaced samples indicates that the Renault limestone and the "Basin Aux Vases" (upper Mississippian) of the Indiana subsurface are equivalent to the Paoli limestone, Aux Vases formation, and the upper part of the Levias member of Ste. Genevieve limestone of Indiana outcrop. "Basin Aux Vases" is equivalent to the Rosiclare sandstone member of Ste. Genevieve of southern Illinois outcrop and occurs stratigraphically above Indiana outcrop Rosiclare.

The upper and lower members of the Renault limestone are persistent, but the "Benoist sand" phase of middle Renault is present only in extreme western Indiana. In the "Basin Aux Vases", characteristic lithologic types occur as north-south belts of sandstone, limestone, and dolomite, respectively, from west to east. Lithologic variations in the "Basin Aux Vases" are series of restricted lenses rather than facies changes. The Aux Vases formation of the Indiana outcrop occurs within the lower Renault but is restricted to the eastern part of the Renault limestone area.

The Renault limestone and "Basin Aux Vases" thin from a total of 120 feet in Posey County to an average of 45 feet on outcrop in Indiana. Carbonate rocks increase in percentage from west to east primarily because of eastward pinch-out of clastic lenses within the middle Renault and the "Basin Aux Vases". Petroleum production is mainly from the "Basin Aux Vases". Oil in the lower Renault limestone has migrated from limestone in the underlying "Basin Aux Vases". Oil production from the "Benoist sand" is limited in Indiana because of restricted occurrence of the sand.

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CROSS-BEDDING AND SANDSTONE TRENDS IN THE CHESTER ROCKS OF THE ILLINOIS BASIN

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Using a standard sampling plan and field technique, the writers measured the direction of dip of one to eight foresets at 471 localities along the arcuate outcrop of the Chester Series (Upper Mississippian) on the west, south, and east sides of the Illinois basin. Thirteen stratigraphically distinct sandstone units are represented. The mean azimuth of 1347 cross-bedding measurements is 215°, which correlates well with the typical northeast-southwest grain of subsurface Chester sandstone bodies and corroborates the southwestward regional slope now documented from early Mississippian into the Pennsylvanian. Preferred orientation of cross-bedding is strong in the thicker sandstones in line with major subsurface trends and is weak to nonexistent in thin shaly sandstones remote from the major trends. Preferred dip is somewhat centripetal, southward along the west margin and nearly westward along the east margin of the basin. This variation in direction suggests that sediment moving down the regional slope was funneled toward the weak tectonic sag of the developing basin.

POSTULATES EMPLOYED IN A PENNSYLVANIAN PALEOECOLOGICAL STUDY*

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Chicago Natural History Museum, Chicago, Ill.

The writers are studying a Pennsylvanian black shale overlying Coal IIIA (Linton formation) in Parke County, Indiana, to determine with greatest possible precision the environment at the time of its deposition. A characterization of the environment, with evidence briefly stated, and with certain postulates on which conclusions are based, is as follows:

Environment	*Evidence*	*Postulates*
Shallow sea	Early stage of transgression across nearly flat land	Gentle change of level more probable than sudden change
Very quiet water	Shale is very fine-grained and finely laminated; elongated fossils show no preferred orientation.	Fine-grained indicates slow current. Lamination is equivalent to bedding. Separation of beds on smooth planes indicates lack of bottom disturbance. Currents would move elongated fragments into preferred orientation.
Warm water	Pennsylvanian climate is considered warm by paleobotanists. Abundance of carbon.	Carbon indicates fast-growing and, fast-decaying vegetation. Rapid growth requires warmth.
Connected with open ocean	Cephalopods are abundant.	Cephalopods are exclusively marine.
Communication with open ocean restricted	Fauna of sharks, etc., is not widespread. Water was very quiet.	If these forms lived over normal marine sediments they would be preserved. Open sea may be disturbed by storms, tides, and currents.
Bottom mud was toxic.	Shark's front part, presumably buried in mud, well preserved; hind part, presumably projecting into water, destroyed.	Anaerobic bacteria in mud and aerobic bacteria in water behave like modern counterparts.

Other conclusions, evidence, and postulates may be listed. The question of validity of postulates is raised and presented for discussion.

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SUBSURFACE SOURCES OF WATER IN THE GLACIAL DRIFT OF INDIANA

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Subsurface bodies of glacial material sufficiently permeable to permit the movement and storage of water are present in the glaciated part of Indiana. Water-bearing formations, or aquifers, in the drift are generally accessible for use and ordinarily supply dependable quantities of water of uniform quality. These aquifers are of scientific interest as well as economic importance.

SAND AND GRAVEL RESOURCES OF INDIANA

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The unglaciated part of Indiana, about 5700 square miles in the south-central part of the state, constitutes only about 15 per cent of the total area of Indiana, and within this unglaciated area only one county (Orange County) has escaped the effects of Pleistocene continental glaciation. Therefore the sand and gravel resources of Indiana are predominantly of glacial origin. Most of the sand and gravel deposits of commercial value in both the glaciated and unglaciated areas are valley-train deposits. However, in northern Indiana numerous commercial deposits are located on outwash plains, and in the central part of the State there are a few esker deposits. Only a small proportion of the sand and gravel deposits was laid down directly by the ice. These are located mainly in the Valparaiso morainic system in the extreme northwestern part of the State.

Most of the sands and gravels consist chiefly of calcareous rock types. This is to be expected, since limestones and dolomites constitute most of the bedrock outcrops in Indiana. The calcareous sands and gravels generally are satisfactory when used as construction materials. In certain areas, however, the sands and gravels contain large amounts of deleterious materials which cause the deposits to be unsatisfactory for construction purposes. These deleterious substances include chert found in the sands and gravels of southwestern Indiana and shale found in the deposits of the Valparaiso moraine.

PETROGRAPHY OF WISCONSIN TILLS IN ORIENTED SECTIONS

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The petrography of Wisconsin till in eastern Ohio and western Pennsylvania was studied in oriented thin sections. These sections show clearly the textural, compositional, and weathering differences between late and early Cary tills. The thin sections also show that the till possesses a microfabric consisting of: (1) microfoliation, which is a parallel arrangement of elongate silt particles; (2) veining, which is a veinlike structure produced by shearing at an angle to the microfoliation; and (3) sand-grain orientation. Microfoliation and sand-grain orientation are nearly horizontal in space and roughly parallel to the direction of ice movement. The pattern of shear fabric suggests that it developed by compaction of the till or by the overriding of a younger ice advance. The fabric can best be seen by use of a gypsum plate. Color photomicrographs show excellently the various fabrics and their characteristics.

PLEISTOCENE-WISCONSIN DEPOSITS AND SOILS OF UPPER WHITEWATER BASIN, INDIANA-OHIO

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Soils of upper Whitewater Basin occur on medium-textured Wisconsin tills of at least two substages that overlie Sangamonian paleosol on Illinoian till. The Wisconsin tills average about 35 per cent limestone plus dolomite. Size fractions have different proportions of calcareous material as follows: coarse sand and gravel, 70 per cent; medium and fine sand, 25 per cent; very fine sand, 40 per cent; silt 30 per cent; and clay, 15 per cent. Loess, dominantly of silt-sized particles, is an im-

portant component of Russell soils and a less important one in Miami soils; it mantles some of the glacio-fluvial terraces. Since loess has less carbonate and greater exposed surface per unit of weight than the coarse material, the depth of leaching in Russell silt loam averages about 1½ times that in Miami silt loam which has thinner loess. This and other evidence so far accumulated in the upper Whitewater Valley indicate that the slight difference in age between Russell and Miami soils has contributed little to the depth of leaching. Northward from Leverett's Bloomington moraine, depth of leaching is only half to three-quarters that of Miami silt loam except where lacustrine silt was deposited from the many small ice-border lakes, not heretofore generally recognized by soil surveyors. Seepage waters from thin aquifers intercalated with tills have caused dark Humic Gley soils to form on steeper slopes than it usually does.

INDIANA'S PROBABLE CLIMATE DURING THE GLACIAL PERIOD

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Climate of Indiana (1944), *Climatic Atlas of the United States* (1954), *Climatic Changes, their Nature and Causes* (1922, with co-author), and several other papers by the writer afford the basis for the following statements.

Indiana's summers during glaciation were relatively warm, induced rapid melting, and permitted considerable vegetation in areas not ice-covered. The winds blowing off the ice averaged relatively cold and drying, whereas those blowing onto the ice from the south yielded much cloudiness and precipitation. As a result of local cooling induced by the ice, there was more rainfall during the warmer months and much more snowfall near the margin of the ice. There were more frequent and sharper changes of weather. The length of the frost-free or growing season presumably was shorter than at pesent because of the sharp cooling that occurred for a considerable distance from the ice as a result of the off-the-ice winds which prevailed approximately a third of the time. The air-mass fronts frequent along the glacial margin increased thunderstorms and their severity. Flood frequency was increased by the rapidity of melting in warm and rainy weather. The Wabash, White, Whitewater, and various other valleys were widely filled with raging torrents during much of the year. In cold weather, the valleys carried little water and instead had broad flats from which much dust was picked up by strong northwest winds. Considerable loess deposits accumulated east of the lower Wabash Valley.

During the interglacial epochs, the climate differed little from the present, though one epoch was drier and another was warmer than at present.

LATE PLEISTOCENE BIOTIC CHANGES IN INDIANA*

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In the zone near the margins of the Pleistocene ice sheets glacial erosion so greatly diminished that fossiliferous proglacial silts have been preserved beneath till in many places in central Indiana. Most of these fossiliferous silts contain assemblages of land mollusks. Quantitative examination of these fossil assemblages has resulted in an interpretation of the vegetation and climate near the ice margin for each glacial advance.

Proglacial silts at the base of drift of both Kansan and Wisconsin age in central Indiana contain abundant snail faunas that indicate that the vegetation around the margin of the glacier provided adequate cover for colonies of woodland snails. The species found in these sediments now live in moist deciduous woodland in the area extending from the Great Lakes northward to central Ontario. Abundant spruce, birch, and willow fragments in this group of deposits also indicate that the advancing ice overrode a forest cover.

When the melting glacier exposed freshly deposited till, the pioneer plants and mollusks that

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became established were nonforest species that now can be collected along and poleward from the northern limit of forest in subarctic Canada. The climax cover for the prevailing climate at the ice margin was boreal forest. The tundra biotic communities migrated northward with the retreating glacier.

CORRELATION AND STRUCTURAL INTERPRETATION OF THE MISSOURIAN AND VIRGILIAN SERIES IN SOUTHWESTERN IOWA

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Recent exploratory operations in Southwestern Iowa have supplied much subsurface information which makes necessary a re-evaluation of the structure and stratigraphy of the Middle River traverse of Madison and Adair counties, Iowa.

Condra and Upp (1933) interpreted the northwestern end of the traverse as being synclinal. The structure is here interpreted as being an anticlinal complex and a part of the "Redfield anticline".

Re-evaluation in stratigraphy includes re-correlation of surface outcrops and a re-definition of selected units between the top of the Oread formation and the base of the Cherryvale formation.

WISCONSIN GLACIAL DEPOSITS OF NORTHEASTERN OHIO

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Co-operative investigations by the Ohio Division of Water and the U. S. Geological Survey have shown that several sequences of Wisconsin deposits exist in northeastern Ohio. The southern part of Summit County near Akron is covered by very coarse early Wisconsin (Tazewell?) drift. West of Akron, the ice of the Killbuck lobe of early Cary age deposited fairly coarse drift. The Grand River lobe, marked by the strong marginal Kent moraine, deposited similarly coarse early Cary drift east of Akron. The lobes joined in southern Summit County and Stark County but did not cover the Akron region. The Wabash-Fort Wayne moraine enters the area from the Till Plain but is overridden north of Akron by later Cary deposits. A moraine that reappears from beneath later Cary drift in northern Trumbull County and southeastern Ashtabula County and adjacent Pennsylvania (the Lavery moraine of Pennsylvania) appears to be of Wabash-Fort Wayne age.

A marked ice readvance is recorded by a deposit of clay-rich till in the northern part of the area and in the central part of the Grand River lobe. On the extreme west and east the margin is marked by the Defiance moraine, but elsewhere the clay till extends far beyond that moraine. The Lake Escarpment System, composed of coarser till than the Defiance, extends from Cleveland to Pennsylvania.

Many outcrops in the area show a sequence from the surface of: Defiance clay till, Fort Wayne-Wabash (Lavery) silty till, Kent silty-sandy till, and Tazewell (?) sandy till. A few exposures show Illinoian gravel or till beneath the Wisconsin deposits.

GLACIAL DEPOSITS OF NORTHWESTERN PENNSYLVANIA

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The outermost drift of northwestern Pennsylvania is Illinoian in age; it extends as a 2- to 14-mile wide belt from Ohio northeast across northwestern Beaver, southeastern Lawrence, northwestern Butler, Venango, extreme northwestern Forest, and Warren counties to a point north of Warren where it is overridden by Wisconsin drift. The outer very discontinuous Illinoian drift may be older than the inner more continuous fine-grained till.

The Wisconsin drift at the surface is all of Cary age. The outer margin is marked by the strong Kent moraine which is continuous around the margin of Wisconsin Grand River lobe. The moraine, composed of coarse till and gravel, varies in width from 2 to 3 miles on the north to 10 miles or more

in the south. Massive kame terraces, in most of the deep valleys from the Kent moraine northwestward for 25 miles to the moraines of the Erie lobe, indicate extensive stagnation of the ice. The Lavery moraine of medium-grained till, deposited along the margin of the Erie lobe, extends from New York State across central Erie County and northwestern Crawford County into Ohio; it is about Ft. Wayne-Wabash in age. The Defiance moraine, of fine-grained till, lies just north of the Lavery moraine and partly overrides it at the Ohio line. The Lake Escarpment System of moraines, composed of medium-grained till and some gravel, crosses Erie County just south of Lake Erie. It overrides the Defiance moraine south and east of Erie.

BURIED VALLEY SYSTEMS IN PARTS OF NORTHEASTERN OHIO

John D. Winslow
U. S. Geological Survey

The buried-valley systems of seven counties in northeastern Ohio have been investigated cooperatively by the U. S. Geological Survey and the Ohio Division of Water, because of their importance to the ground-water resources of the area. The buried-valley systems have been delineated from information obtained from the records of wells and from geophysical studies. These drainage systems were developed by the pre-glacial Teays age streams, the Aftonian Deep Stage streams, the Yarmouth-Brecksville stage streams, and the streams that drained the area in Sangamon time. The Teays age drainage is represented by the wide strath cut in the rock surface at an altitude of about 450 feet in Cuyahoga County, and by the buried valleys that underlie Eagle Creek and the West branch of the Mahoning River in Portage County. The Deep Stage drainage is represented by the deep inner gorge, cut to an altitude of about 50 feet below sea level, in the rock floor of the Teays age system in Cuyahoga County. The Brecksville Stage is represented in Cuyahoga County where it crosses the valley courses of the two earlier drainage systems, and also in Portage County and eastern Cuyahoga County where the main north-south part of the drainage system was deeply scoured by Illinoian ice. Little is known of the Sangamon drainage system other than it occupied parts of the earlier drainage systems in the Cuyahoga Valley, Cuyahoga County, and in the valley of Eagle Creek, Portage County.

UPPER MISSISSIPPIAN—LOWER PENNSYLVANIAN MEGASPORES

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Preliminary studies of the megaspores from coals and carbonaceous beds of Upper Mississippian and Pennsylvanian age, principally from Illinois, indicate that studies of spore assemblages might be used to delineate clearly the lower Pennsylvanian boundary in the Illinois basin. Studies specifically devoted to both megaspores and small spores occurring in all types of rocks below and above the Mississippian-Pennsylvanian contact, where it is known with certainty, will be required to determine the worth of such studies.

The oldest Pennsylvanian coals studied contain abundant spinose lageniculate spores, hirsute-flanged spores, and deltoid-bladdered spores. Large spinose aphanozonate spores of sigillarian affinity, saclike lepidocarp spores, and unusual saclike spores of unknown affinity are common; medullosan spores, flanged-reticulate spores of herbaceous lycopods, and seed membranes are also present. The uppermost Chester beds examined contain spinose lageniculate spores and heavy-apexed spinose spores. Absence of spores common to Caseyville coals should not be relied upon too heavily, but as yet none of the medullosan, sigillarian, flanged-reticulate, or deltoid-bladdered spores has been observed in Chester age rocks.

Although some megaspores in the Chester are closely allied to those in the Caseyville, most are distinguishable on the basis of ornamentation differences. The megaspores, and undoubtedly also the small spores, from the lower part of the Chester and from older beds are clearly distinguishable from Pennsylvanian spores.

ABSTRACTS OF PAPERS SUBMITTED FOR THE MEETING IN ANCHORAGE, ALASKA, SEPTEMBER 10–13, 1957 (EIGHTH ALASKAN SCIENCE CONFERENCE OF AAAS)

AEROMAGNETIC STUDY OF THE COPPER RIVER BASIN, ALASKA

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An aeromagnetic survey was made of approximately 6000 square miles of the Copper River Basin, Alaska, in 1954 and 1955. North-south flight lines spaced a mile apart were flown from Lat. 61°45′ to 63°00′N. The eastern and western borders of the surveyed areas are at Long. 145°00′ and 147°22′W.

The magnetic patterns closely parallel the generally east-west arcuate geologic "grain" and seem to correlate with lithology and with geologic structure. Outcropping areas of volcanic rocks are reflected by the configuration of the magnetic contours. A large area of low-amplitude magnetic anomalies extends from the Chugach Mountains north to about Lat. 62°30′N. This area may possibly outline a structural basin of Tertiary age superimposed upon a depositional and structural trough of Jurassic and Cretaceous age. Anomaly-producing rock masses within this area are estimated to be a mile or more beneath the surface and are interpreted to be most deeply buried beneath the southern part of the Copper River Basin.

The magnetic data suggest that lower Jurassic volcanic rocks exposed in the Talkeetna and Chugach mountains underlie the marine and nonmarine sedimentary rocks of the southwestern part of the surveyed area. The change in the magnetic pattern at the northern front of the Chugach Mountains is caused by a contact between these volcanic rocks and the younger sedimentary rocks to the north. The magnetic data suggest that the Wrangell lavas of Tertiary and Quaternary age are present at shallow depths beneath the basin in the vicinity of Mount Drum.

SEA-LEVEL STUDIES AT POINT BARROW, ALASKA

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As a part of the IGY Sea-Level Study, a tide station suitable for arctic use has been designed and installed at Point Barrow. The tide station is of unusual design in that it utilizes an unfrozen "aquifer" of highly permeable gravel to transmit changes in water level in the ocean to the tide station, which is on land and out of range of the ravages of moving sea ice.

Analysis of 6 months of tide records from the Barrow station reveals, in addition to the astronomic tides, changing sea levels on three time scales: (1) a 20- to 30-minute oscillation of small amplitude; (2) daily changes of up to 2 feet; (3) monthly changes of up to 5 inches.

Recent Russian sea-level data from the Siberian arctic are presented for comparison.

RECOLLECTIONS OF EARLY OIL EXPLORATION IN ALASKA

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Up to 1938 a total of 64 wells had been drilled for oil in Alaska. Of these, 21 were commercial producers in their day; all were in the Katalla field which was closed in 1933 because of loss of a part of the refinery. Exploration started in 1901 and proceeded intermittently. Much of the difficulty prohibiting orderly development was due to oil and gas permits or leases being tied into placer and coal-mining laws and regulations. By and large, exploration up to 1938 was not historically discouraging and compares favorably with other areas.

CLIMATIC ANALOGS OF FORT GREELY AND FORT CHURCHILL IN THE NORTHERN HEMISPHERE

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Fort Greely, Alaska, and Fort Churchill (Manitoba), Canada, are utilized by the Armed Forces of the United States as cold-weather test sites where suitability and capability of clothing and equipment for cold-climate operations are determined. This study undertakes to delimit the extent to which the climate of each site is representative of arctic and subarctic areas throughout the world.

The climatic elements studied are those considered most significant from the standpoint of human stress in cold environments. The complete series includes maps of mean and mean daily minimum temperatures for the coldest month, absolute minimum temperatures, mean and mean daily maximum temperatures for the warmest month, mean annual precipitation, mean windchill for the coldest month, mean cloudiness for the warmest and the coldest months, mean snow depth for the month of maximum depth, and (for North America only) mean snowfall for the month of greatest fall. In addition three composite maps were prepared showing where areas of analogy of various climatic elements coincide.

Both North America and Eurasia have considerable areas wherein the values for climatic elements studied are closely analogous to those at either or both of the test sites. These areas lie, for the most part, north of the 45° parallel.

IGY RESEARCH PROGRAM ON McCALL GLACIER, BROOKS RANGE, ALASKA

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The Brooks Range extending east-west across extreme northern Alaska forms a topographic barrier having a profound effect on climates both of the Alaskan interior and of the north slope. Near the eastern end of the range, close to the Canadian border, stand the highest peaks of the range, the Romanzof Mountains, with elevations between 8000 and 10,000 feet. The Romanzof Mountains contain the only significant glaciers in the Brooks Range. Most of these glaciers are small alpine-valley types ranging from 1 to 6 miles in length and having a cumulative area of perhaps 100 square miles.

A survey of these glaciers shows that in the last several decades they apparently have not experienced the extensive shrinkage found generally elsewhere in Alaska. On the other hand, these glaciers are thermally polar and, therefore, are very likely to respond differently to climatic changes from the more common thermally temperate glaciers which predominate in Alaska. Because most of the basic features of the dynamics of polar glaciers have not yet been investigated, it was evident that a full program of geophysical research on a typical glacier of the region was needed.

An IGY station is being operated on the McCall Glacier in the Romanzof Mountains for the period from May 1957 through September 1958. The program of studies includes micrometeorology, snow and ice stratigraphy, glacier movement, and thermal structure within the glacier.

ALASKAN EVIDENCE IN SUPPORT OF A POST-ILLINOIAN PRE-WISCONSIN GLACIATION

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Radiocarbon dating of the Naptowne glaciation in the Cook Inlet region indicates that it is more likely the correlative of all, not just part, of the Wisconsin and Weichsel stages of the continental-type Pleistocene chronologies. This correlation thus provides a firm time boundary against which pre-Naptowne events may be compared with the type sequences on the basis of available evidence bearing on relative age and rank.

The pre-Naptowne Knik glaciation is recorded by glacial deposits that lie beneath and just beyond the outermost Naptowne moraines. Buried soils exposed near Anchorage and elsewhere in the Cook Inlet region record major retreatal intervals preceding as well as following the Knik advance. Boulder counts and geomorphic expression of moraines are consistent with the stratigraphic evidence in suggesting significant and roughly equal age differences between the Naptowne, Knik, and the earlier and more extensive Eklutna glaciation.

Comparable morainal sequences are described from the continental-type sections which also record significant stratigraphic breaks between the Illinoian-Saale, "X" glaciation-Warthe, and Wisconsin-Weichsel deposits. The recently recognized pre-Farmdale, post-Illinoian "X" glaciation in the United States coincides in stratigraphic position with the Knik and Warthe glaciations. To consider this event early Wisconsin in age, as suggested in the literature, requires a major and unnecessary revision in the type-section definition of the Wisconsin as beginning with the Farmdale substage, and negates the available and consistent evidence that the Knik and correlative events are of comparable, not subordinate, rank to the Wisconsin glacial stage.

PERIODIC HEAT FLOW IN A STRATIFIED MEDIUM WITH APPLICATION TO PERMAFROST PROBLEMS

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Solutions to the Fourier heat equation for quasi-steady periodic flow in a stratified semi-infinite medium can be obtained readily by standard methods. The results have wide application to studies of earth-temperature variations induced by diurnal, annual, and other periodic variations in temperature at the ground surface. Much of the previous work on this subject has been interpreted by reference to the solution for the homogeneous case, which often results in appreciable error when applied to stratified earth materials.

One application of the theory is to the important problem of determining the minimum thickness of gravel fill required to maintain the material on which it rests (the subgrade) in a perennially frozen state in permafrost areas. The results indicate that the thickness of the required fill is quite sensitive to the thermal properties of the subgrade. If a thin layer of material with low thermal contact coefficient, such as spruce logs, is placed between the fill and subgrade, the thickness of fill required to maintain undisturbed permafrost can be greatly reduced.

The thermal properties of the soil beneath the layer supporting plant growth can exericse an important influence on the temperatures in that layer. This effect, which cannot be explained by studies of the ground surface and the surficial layer, is likely to have important application to plant ecology in the arctic.

The theory yields an approximate method of estimating the effect of winter snow cover on the mean annual temperature of the ground surface.

ORIGIN OF THE PT. CAMPBELL-PT. WORONZOF AREA AS RELATED TO THE "BLUE CLAY" THAT UNDERLIES ANCHORAGE, ALASKA

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Stratified deposits of cobbles, pebbles, sand, silt, and clay of probable deltaic origin are exposed along Turnagain Arm and southeast of Pt. Woronzof along Knik Arm. The deposits form a ridge about 4 miles long and 125 to 150 feet higher than the general level of the drift plain and that extends from Pt. Campbell on Turnagain Arm to Pt. Woronzof on Knik Arm. The ridge is broken by a saddle that separates Pt. Campbell from Pt. Woronzof. Blue-gray silty clay of probable lacustrine origin is exposed along Knik Arm and appears to interfinger with the deltaic deposits. The blue-gray silty clay extends southward and underlies younger deposits in the vicinity of Anchorage.

The source of the deltaic deposits was probably a glacier that moved from the west or northwest. The deposits contain till blocks locally and abundant fragments and lenses of alluvial coal. The presence of the till blocks indicates proximity of the ice, which would have dammed and ponded the meltwater from the

Matanuska and Knik glaciers. Because no coal is known up Turnagain Arm, the glacier was perhaps a lobe from either the Susitna Valley glacier or a glacier from the Alaska Range on the west side of Cook Inlet. The blue-gray silty clay is probably the fine-grained fraction of the load contributed to the lake by the glaciers to the north at the same time that the delta was built northward from the ice dam.

PLEISTOCENE HISTORY OF THE ANCHORAGE AREA, ALASKA

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The oldest glacial drift exposed in the Anchorage area is Illinoian(?) in age. Advance of the Matanuska and Knik lobes of the Susitna Valley glacier of probable post-Sangamon but pre-Wisconsin age (Knik glaciation of Karlstrom) buried this drift beneath till and outwash that is exposed along Knik Arm north of Anchorage, along the lower slopes of the Chugach Mountains, and in the lowlands south of Anchorage. The fine-grained fraction of the outwash from this retreating glacier (the "blue clay" exposed along Knik Arm) accumulated in the ponded water dammed by a glacier from the west or northwest. A peat deposit that is correlated with the interglacial weathering on the "blue clay" is dated at older than 38,000 radiocarbon years (W-535).

A glacial advance of Wisconsin age earlier than the last Wisconsin advance is suggested by a till that separates the "blue clay" from the uppermost glacial deposits (Naptowne of Karlstrom). Deposits formed during the retreat and stagnation of the last Wisconsin glacier extend northward from the end moraine north of Anchorage. Meltwater from the Eagle River glacier was diverted southward by the last Wisconsin glacier or its end moraine and deposited outwash dated at 11,600 ± 300 radiocarbon years (W-540) over the present area of Anchorage. These waters later changed channels and cut Fossil Creek as well as other presently abandoned meltwater channels tributary to the modern Eagle River.

Erosion by waters of the combined Matanuska and Knik rivers, coupled with erosion by encroaching Cook Inlet waters, produced a channel into the outwash and "blue clay" that became Knik Arm. Similar erosion formed Turnagain Arm.

LIMITS OF DITHIZONE AS AN INDICATOR FOR HEAVY METALS

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Dithizone (diphenylthiocarbazone) is used as an indicator for the colorimetric analysis of trace quantities of heavy metal. It behaves as mono- or dibasic acids under certain conditions and forms metal dithizonates. Generally, each metal dithizonate has a characteristic color which identifies the metal. However, the determination of metal concentration depends on metal-dithizone equilibrium, pH, the nature of sample, existence of metal dithizonate in enol or keto form, and the valency of metals.

Dithizone is susceptible to oxidation by heat and light. In solution it oxidizes at a faster rate than in solid form. The greater the dilution of the solution the faster is the rate of oxidation. The oxidized dithizone (diphenylthiocarbondiazone) does not react with any metal and therefore is not suitable for colorimetric analysis. The rate of oxidation can be decreased by certain reagents in the dithizone solution or in the aqueous layer in contact with the dithizone solution.

PRELIMINARY REPORT OF THE 1957 ADVANCE OF MULDROW GLACIER, ALASKA

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Muldrow Glacier on the north flank of Mount McKinley in the Alaska Range is vigorously advancing. The lower 20 miles of the 35-mile-long glacier had been wasting downward for the last 100 years. In January 1957 the U. S. National Park Service noticed that the lower part of the glacier was thicker and more

crevassed than it had been the preceding year; this unusual condition was not reported to a geologist until June. The front moved about 20 to 30 feet per day between June 20 and July 27. By July 27, 1957, the glacier front had advanced at least 3.8 miles from its position in the fall of 1956. The lower half of the glacier has greatly thickened, and the surface is very rough and jagged because of crevasses and 50-foot-high pinnacles of ice. Much of the 100-year-old ice-cored moraine has been broken into jagged blocks and incorporated into the moving ice.

Below Gunsight Pass, for a distance of 10 to 15 miles, Muldrow Glacier has subsided about 100 feet, leaving an ice ridge clinging to the north valley wall. The surfaces of the upper Muldrow and lower Traleika glaciers have broad wavelike configurations.

Other major glaciers in this part of the range show no new activity. Climatic data from several low-altitude stations north and south of the range indicate no long-term increase in precipitation. Mountain climbers state that the surface of upper Muldrow Glacier has become increasingly more crevassed in the last 6 years. Much of the Muldrow glacial trough lies along a major fault.

RECENT HISTORY OF GLACIATION IN THE MALASPINA DISTRICT AND ADJOINING BAYS, ALASKA

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The following history of advance and retreat of the Malaspina Glacier and the glaciers discharging into Icy Bay and Yakutat Bay is inferred from recent field investigations and study of aerial photographs, from historical records, and from radiocarbon dates:

(1) Older advance culminating between 600 and 1290 A. D. in a nearly continuous tidal ice front extending from the west side of Icy Bay to the southeast side of Yakutat Bay.

(2) Recession between 1400 and 1700 A.D. to positions at or north of the present ice fronts.

(3) Younger advance culminating between 1700 and 1791 A.D. in tidal ice fronts at the mouth of the present Icy Bay and the re-entrant between this lobe and the Malaspina Glacier (the Icy Bay of Vancouver?), at Sitkagi Bluffs, and at Blizhni Point in Yakutat Bay.

(4) Recession of the Yakutat Bay lobe and stagnation of the Malaspina Glacier margin beginning before 1791 A. D. and continuing, with minor interruptions, to the present. Recession of the Icy Bay lobe, beginning about 1904 A. D.

Recently determined radiocarbon dates for wood embedded in the outermost end moraines at the west side of Icy Bay (W-374) and southeast side of Yakutat Bay (W-559) are, respectively, 1,200 ± 160 years B. P. and 830 ± 160 years B. P. These moraines record the maximum advance of glaciers on the present coastal lowland.

OIL AND GAS FIELDS OF NAVAL PETROLEUM RESERVE NO. 4 AND ADJACENT AREAS, NORTHERN ALASKA

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Three oil fields and two gas fields were discovered by the U. S. Navy in Alaska from 1944 through 1953. Umiat field, 175 miles southeast of Point Barrow, is a faulted anticline with 800 feet of closure within an area 9 miles long and 2 miles wide. Eleven test wells were drilled, 7 of which produced paraffin-base, 36° API gravity oil from rocks of Early Cretaceous age. Reserve estimate is 60,000,000 barrels.

Simpson Seeps oil field is a stratigraphic trap 50 miles southeast of Barrow. Twenty-two core tests were drilled near three large oil seeps within an area of about 30 square miles. Nineteen degree API gravity oil was produced from sandstones of Late Cretaceous age which underlie a subsurface unconformity of several thousand feet relief.

In the Fish Creek oil field a single well was pumped at a rate of 10 barrels of 13.9° API gravity oil per day from Early Cretaceous siltstones. Little is known about the structure.

Wells in the Barrow gas field, which produce from a Middle Jurassic sandstone, are located on a fault

block at the side of a cryptovolcanolike structure. Reserve estimates of gas range from 5 to 7 billion cubic feet.

Gubik gas field, 16 miles northeast of Umiat, is a relatively simple anticline with approximately 500 feet of closure. The structure is 14 miles long and 3.2 miles wide and produces gas from two different formations of Late Cretaceous age. Reserve estimate is 222 billion cubic feet.

RELATIONSHIP OF ARCTIC STORMS TO BEACH AND NEAR-SHORE CHANGES AT POINT BARROW, ALASKA

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Sponsored by the Office of Naval Research, Geography Branch, shoreline studies have been conducted since 1954 at Point Barrow, Alaska. Beach material is chert gravel with median diameter up to 15 mm. Offshore, there is rapid decrease in size with medians of 0.2 mm, 400 feet from shore, and increasing proportions of quartz. In the summer of 1954, bottom profiles showed a steep drop with depths of 10 feet, 100 feet from shore, followed by a slope to 20 feet at a distance of 500 feet at one site and 1500 feet at two others. At the latter sites, the surveys of 1955 found a bar 400 feet offshore, rising to within 7 feet of the surface with intervening depths to 14 feet. Abnormally large waves in October 1954 are believed to have built the bar. This storm, the worst in 40 years, developed the unusually large waves because of the extreme withdrawal of the pack ice. The storm tide rose 10 times the 1-foot height of the normal diurnal tide. The unchanged profile is thus indicated to have been in equilibrium with this exceptional storm. Other storms occurring in 1954 and 1956 (pack ice prevented wave action in 1955) have been evaluated with respect to the exceptional storm. Comparisons indicate that, given a profile for this region, it should be possible to predict whether a storm exceeding a critical intensity will have no effect (stable profile) or will throw up a bar (unstable profile).

AEROMAGNETIC RECONNAISSANCE OF THE COOK INLET AREA, ALASKA

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Fourteen aeromagnetic profiles were flown east-west across the Cook Inlet area in 1954, nine extending from about the Triumvirate and Capp Glaciers to the Chugach Mountains, and five from the Iniskin-Chinitna Peninsula to the Kenai Peninsula. These profiles show several significant magnetic features that seem to have geologic significance.

The overall arched character of the profiles suggests the existence of a block-shaped rock mass underlying Cook Inlet at great depth. A 1600-gamma anomaly was observed over Mt. Susitna, a granitic intrusion. A two-dimensional anomaly observed over Knik Arm may reasonably be attributed to a zone of buried granitic intrusive rocks continuous with the intrusive cropping out at Eklutna. This intrusive, or zone of intrusives, appears to deepen to the south, reaching estimated depths of 5000 or 6000 feet at the lower end of Knik Arm. Anomalies observed over the Susitna flats indicate that the magnetic basement is buried some 12,000 to 14,000 feet.

An abrupt magnetic rise of 300 to 400 gammas observed over the coast line of the Iniskin-Chinitna Peninsula is caused by a significant change in rock type, suggesting the possible existence of a fault with a vertical displacement of several thousands of feet. East of this area, no near-surface anomaly-producing rock masses are present It is likely that here the depth to magnetic basement is very great.

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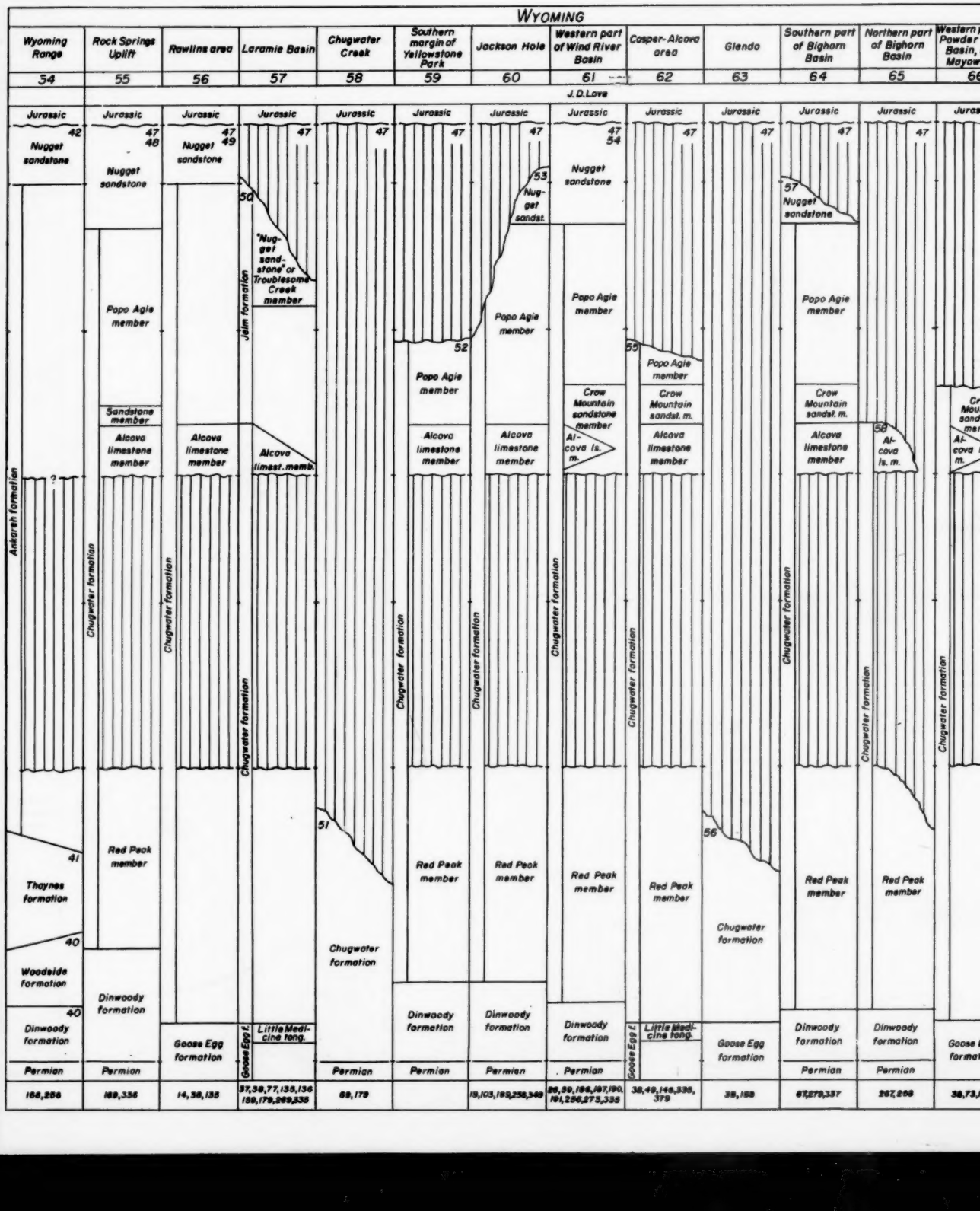

WYOMING
Wyoming Range
34
Rock Springs Uplift
55
Rawlins area
56
Laramie Basin
57
Chugwater Creek
58
Southern margin of Yellowstone Park
59
Jackson Hole
60
Western part of Wind River Basin
61
Casper-Alcova area
62
Glendo
63
Southern part of Bighorn Basin
64
Northern part of Bighorn Basin
65
J.D.Love
Jurassic
Nugget sandstone
Ankareh formation
Thaynes formation
Woodside formation
Dinwoody formation
Permian
Chugwater formation
Popo Agie member
Sandstone member
Alcova limestone member
Red Peak member
Jelm formation
"Nugget sandstone" or Troublesome Creek member
Alcova limest. memb.
Goose Egg f.
Little Medicine tong.
Goose Egg formation
Crow Mountain sandstone member
Alcova ls. m.
Crow Mountain sandst. m.
Alcova ls. m.
168,256
169,336
14,36,135
37,38,77,135,136 159,179,269,335
69,179
19,103,189,258,349
28,89,186,187,190, 191,256,275,335
38,49,146,335, 379
38,188
67,273,337
267,268

Chart 8a. -

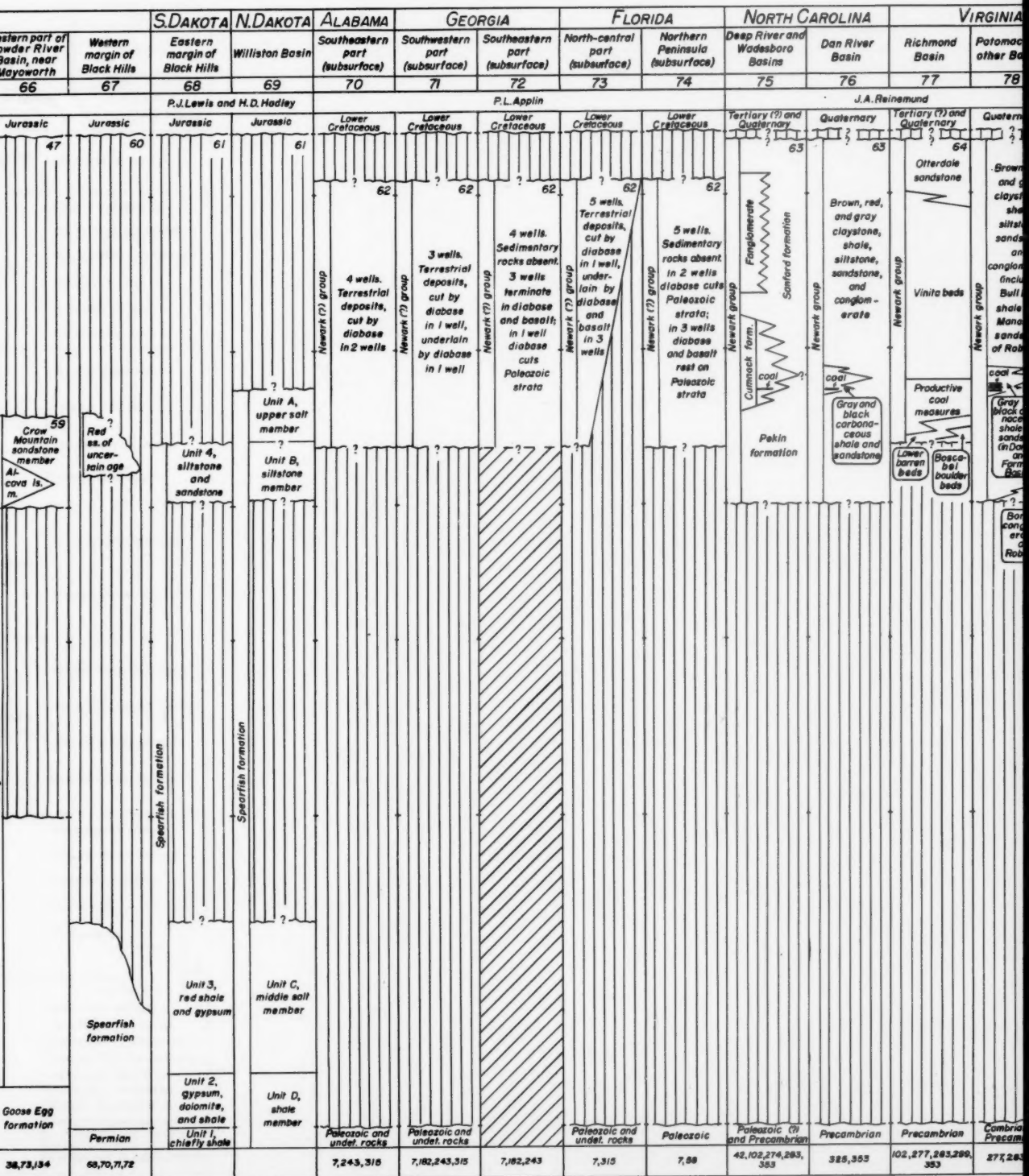
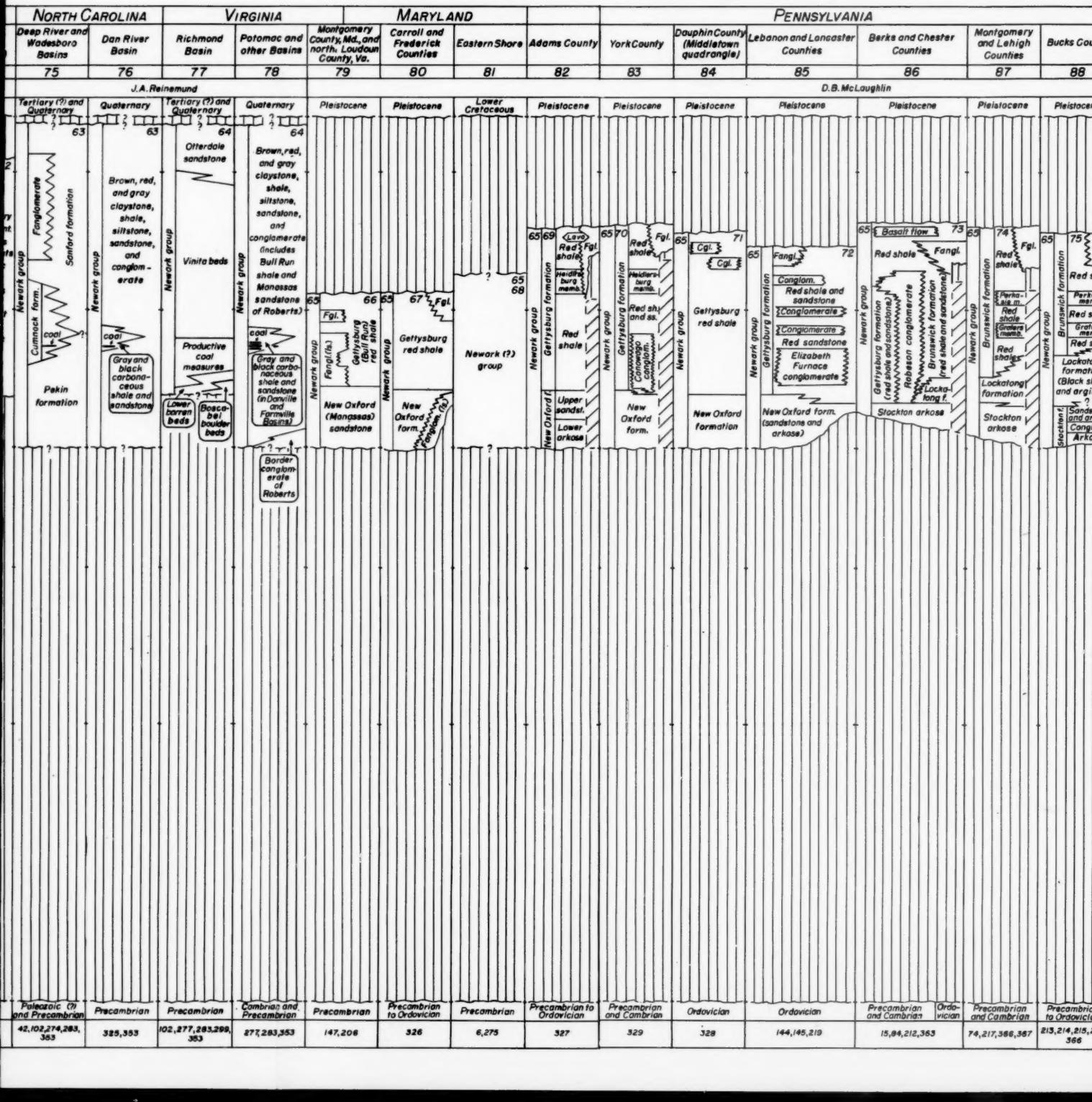

S.Dakota
N.Dakota
Alabama
Georgia
Florida
North Carolina
Virginia
Eastern part of Powder River Basin, near Mayoworth
Western margin of Black Hills
Eastern margin of Black Hills
Williston Basin
Southeastern part (subsurface)
Southwestern part (subsurface)
Southeastern part (subsurface)
North-central part (subsurface)
Northern Peninsula (subsurface)
Deep River and Wadesboro Basins
Dan River Basin
Richmond Basin
Potomac other Ba
66
67
68
69
70
71
72
73
74
75
76
77
78
P.J. Lewis and H.D. Hadley
P.L. Applin
J.A. Reinemund
Jurassic
Permian
Lower Cretaceous
Tertiary (?) and Quaternary
Quaternary
Newark (?) group
Spearfish formation
Goose Egg formation
Crow Mountain sandstone member
Alcova ls. m.
Red ss. of uncertain age
Unit A, upper salt member
Unit B, siltstone member
Unit C, middle salt member
Unit D, shale member
Unit 4, siltstone and sandstone
Unit 3, red shale and gypsum
Unit 2, gypsum, dolomite, and shale
Unit 1, chiefly shale
4 wells. Terrestrial deposits, cut by diabase in 2 wells
3 wells. Terrestrial deposits, cut by diabase in 1 well, underlain by diabase in 1 well
4 wells. Sedimentary rocks absent. 3 wells terminate in diabase and basalt; in 1 well diabase cuts Paleozoic strata
5 wells. Terrestrial deposits, cut by diabase in 1 well, underlain by diabase and basalt in 3 wells
5 wells. Sedimentary rocks absent in 2 wells diabase cuts Paleozoic strata; in 3 wells diabase and basalt rest on Paleozoic strata
Fanglomerate
Sanford formation
Cumnock form.
coal
Pekin formation
Brown, red, and gray claystone, shale, siltstone, sandstone, and conglomerate
Gray and black carbonaceous shale and sandstone
Otterdale sandstone
Vinita beds
Productive coal measures
Lower barren beds
Boscobel boulder beds
Paleozoic and undet. rocks
Paleozoic
Precambrian
Cambria
Precam
38,73,134
68,70,71,72
7,243,315
7,182,243,315
7,182,243
7,315
7,88
42,102,274,283,353
325,353
102,277,283,299,353
277,283

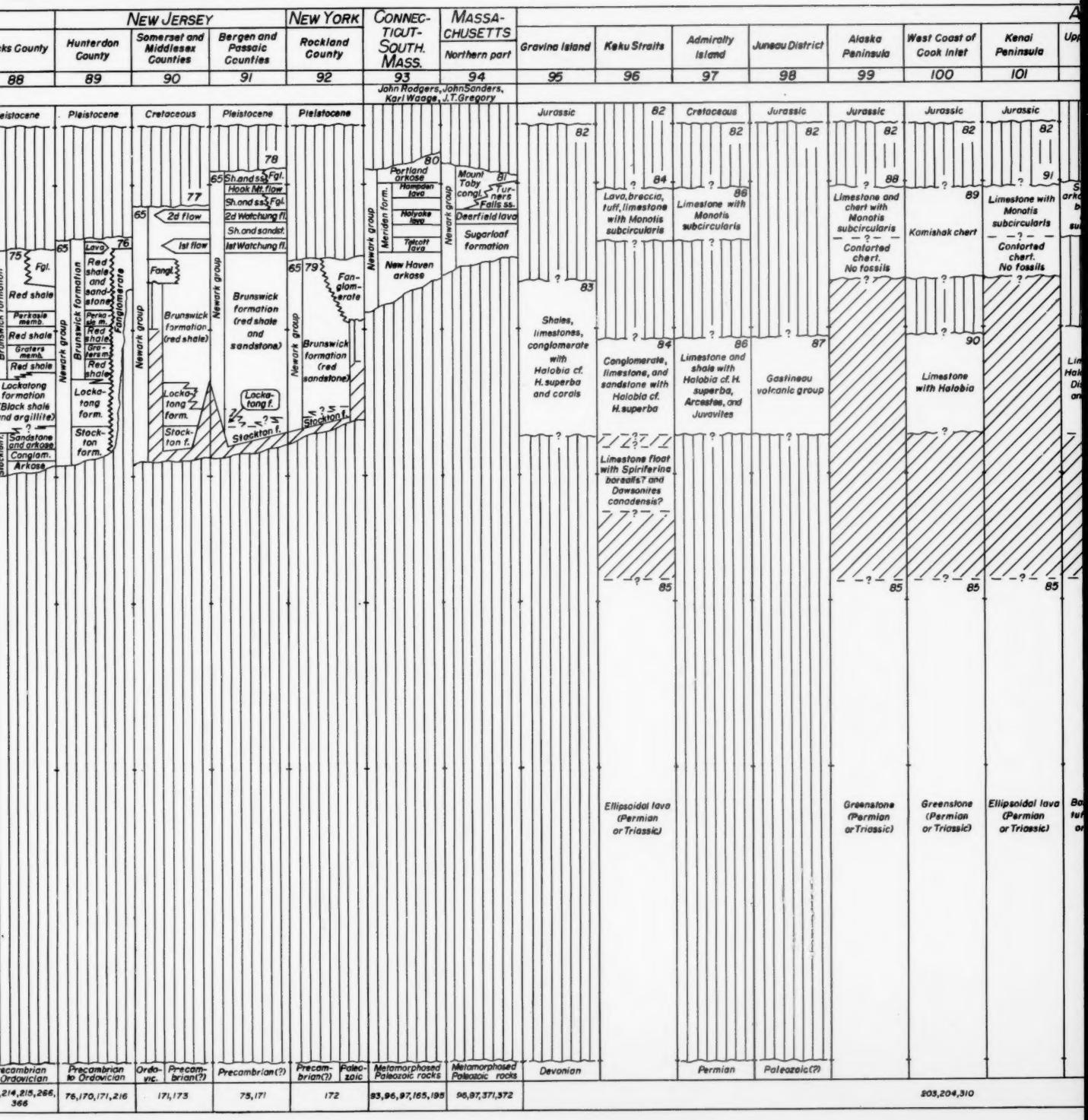
Chart 8a. - CORRELATION OF TRIASSIC FORMATIONS OF NORTH AME

By the Triassic Subcommittee, John B. Reeside, Jr. (Chairman), P. L. Applin, E. H. Colbert, J. T. Gregory, H. D. H
J. D. Love, Manuel Maldonado-Koerdell, E. D. McKee, D. B. McLaughlin, S. W. Muller, J. A. Reinemund, John Rodg



IERICA EXCLUSIVE OF CANADA *(Continued)*

D. Hadley, Bernhard Kummel, P. J. Lewis,
Rodgers, N. J. Silberling and Karl Waage



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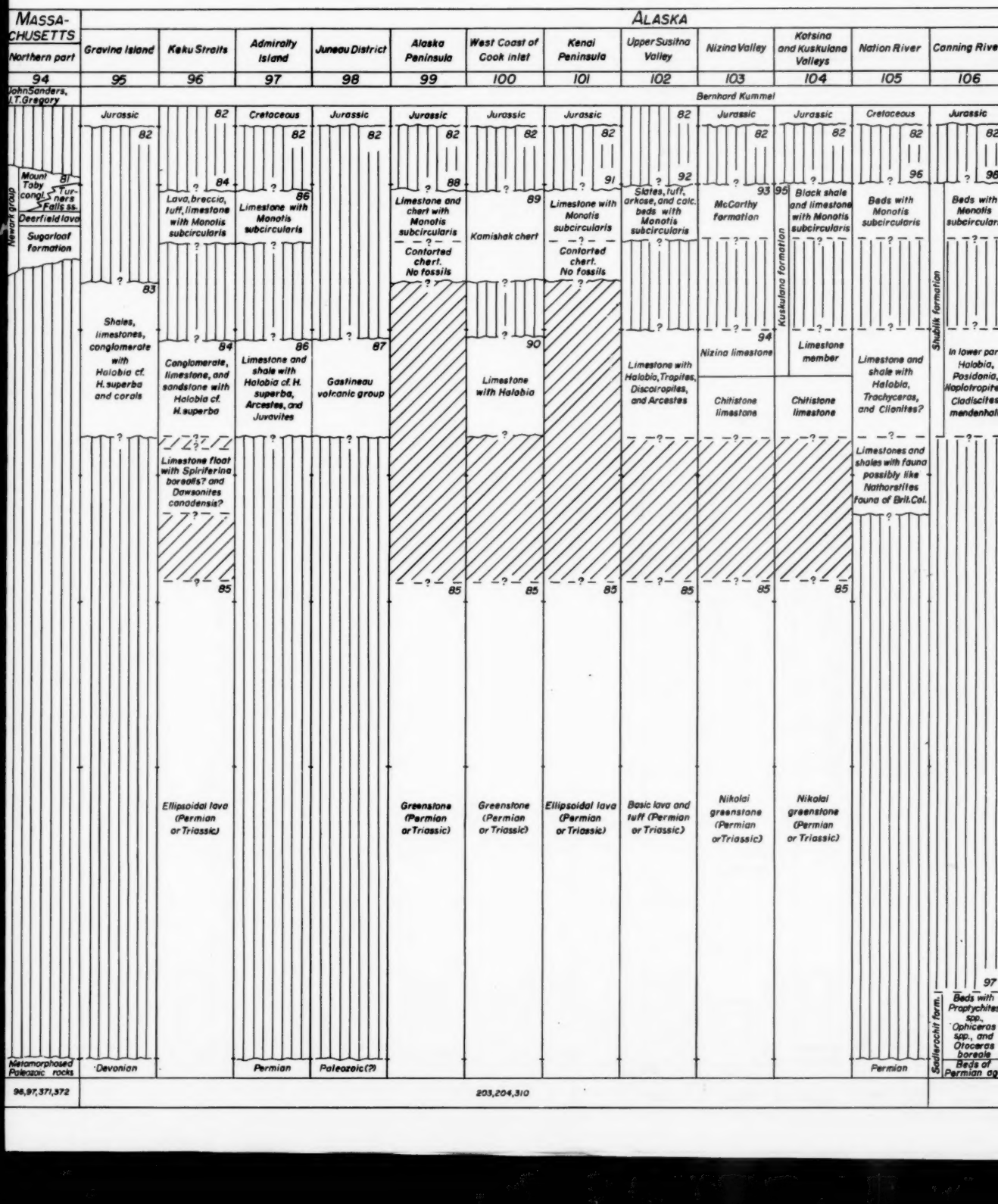
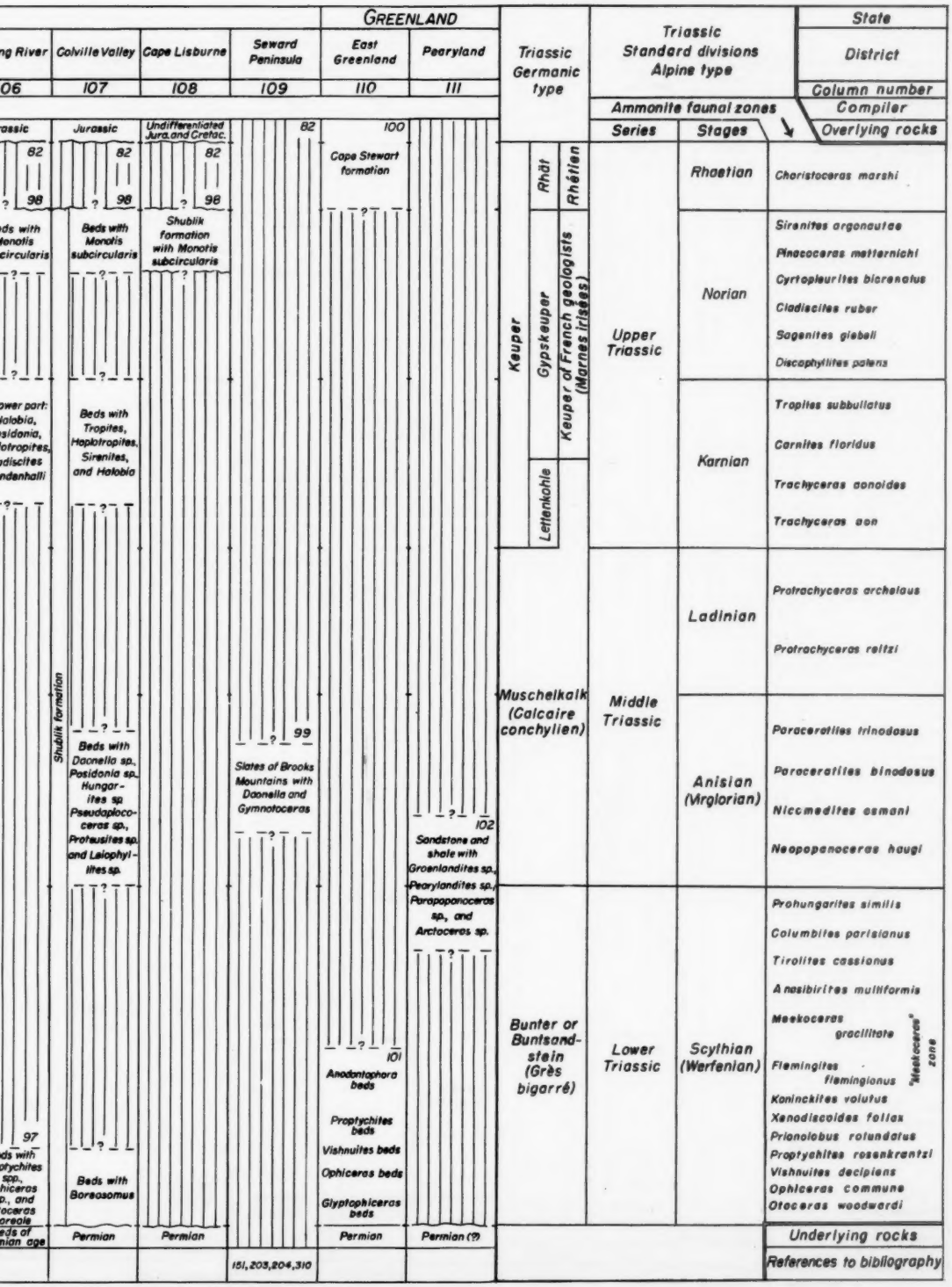
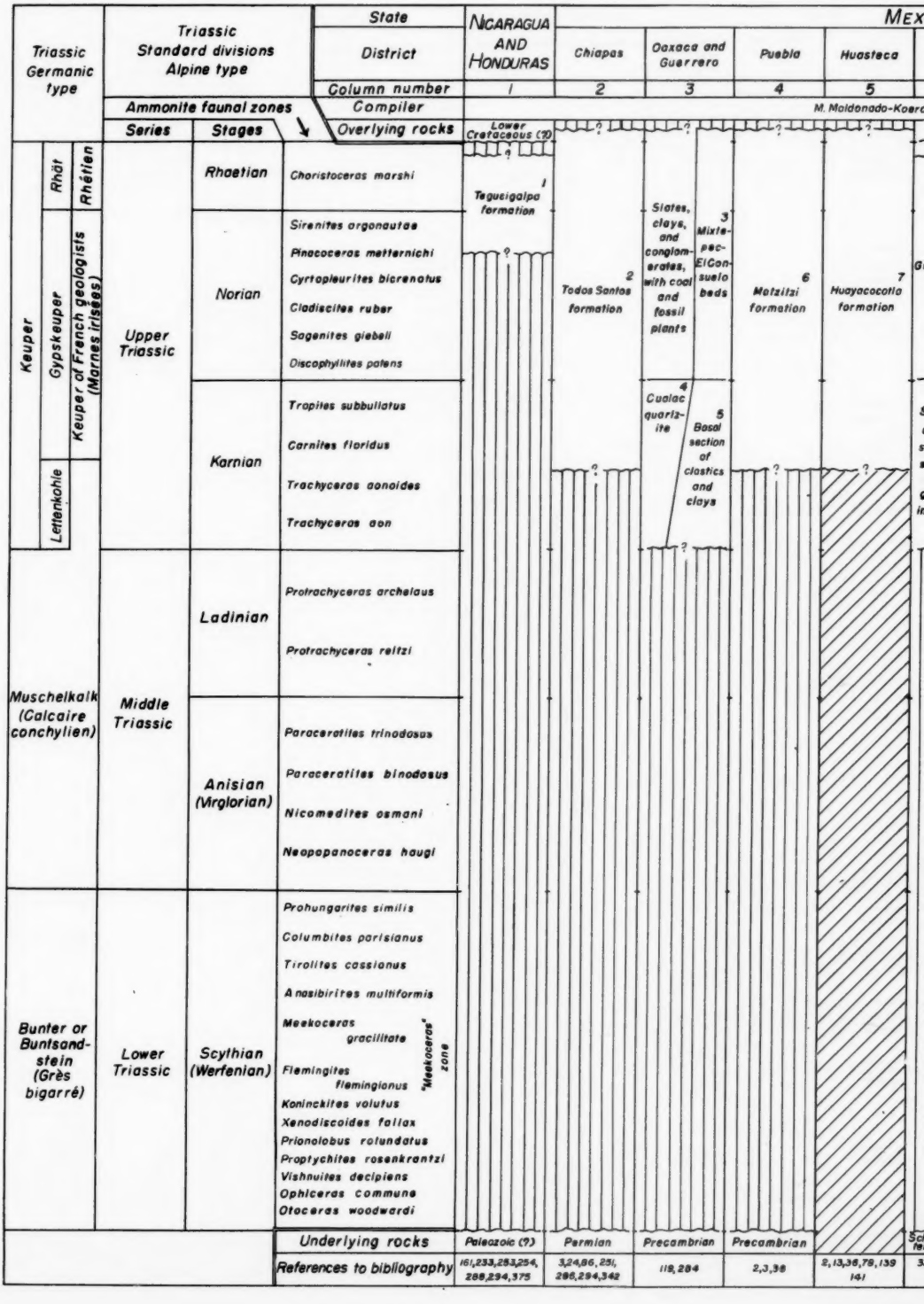

MASSACHUSETTS
Northern part
94
John Sanders, I. T. Gregory
Newark group
Mount Toby congl.
Turners Falls ss.
Deerfield lava
Sugarloaf formation
Metamorphosed Paleozoic rocks
96,97,371,372
ALASKA
Gravina Island
95
Jurassic
Shales, limestones, conglomerate with Halobia cf. H. superba and corals
Devonian
Keku Straits
96
Lava, breccia, tuff, limestone with Monotis subcircularis
Conglomerate, limestone, and sandstone with Halobia cf. H. superba
Limestone float with Spiriferina borealis? and Dawsonites canadensis?
Ellipsoidal lava (Permian or Triassic)
Admiralty Island
97
Cretaceous
Limestone with Monotis subcircularis
Limestone and shale with Halobia cf. H. superba, Arcestes, and Juvavites
Permian
Juneau District
98
Jurassic
Gastineau volcanic group
Paleozoic(?)
Alaska Peninsula
99
Jurassic
Limestone and chert with Monotis subcircularis
Contorted chert. No fossils
Greenstone (Permian or Triassic)
West Coast of Cook inlet
100
Jurassic
Kamishak chert
Limestone with Halobia
Greenstone (Permian or Triassic)
Kenai Peninsula
101
Jurassic
Limestone with Monotis subcircularis
Contorted chert. No fossils
Ellipsoidal lava (Permian or Triassic)
Upper Susitna Valley
102
Bernhard Kummel
Slates, tuff, arkose, and calc. beds with Monotis subcircularis
Limestone with Halobia, Trapites, Discotropites, and Arcestes
Basic lava and tuff (Permian or Triassic)
Nizina Valley
103
Jurassic
McCarthy formation
Nizina limestone
Chitistone limestone
Nikolai greenstone (Permian or Triassic)
Kotsina and Kuskulana Valleys
104
Jurassic
Kuskulana formation
Black shale and limestone with Monotis subcircularis
Limestone member
Chitistone limestone
Nikolai greenstone (Permian or Triassic)
Nation River
105
Cretaceous
Beds with Monotis subcircularis
Limestone and shale with Halobia, Trachyceras, and Clionites?
Limestones and shales with fauna possibly like Nathorstites fauna of Brit. Col.
Permian
Canning River
106
Jurassic
Shublik formation
Beds with Monotis subcircular
In lower part Halobia, Posidonia, Neoplotropites Cladiscites mendenhall
Sadlerochit form.
Beds with Praptychites spp., Ophiceras spp., and Otoceras boreale
Beds of Permian ag
203,204,310

Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*




Triassic Germanic type
Triassic Standard divisions Alpine type
State
District
Column number
Compiler
Ammonite faunal zones
Series
Stages
Overlying rocks
Nicaragua and Honduras
Chiapas
Oaxaca and Guerrero
Puebla
Huasteca
Mex
1
2
3
4
5
M. Maldonado-Koerd
Lower Cretaceous (?)
Keuper
Rhät
Rhétien
Gypskeuper
Keuper of French geologists (Marnes irisées)
Lettenkohle
Upper Triassic
Middle Triassic
Lower Triassic
Rhaetian
Norian
Karnian
Ladinian
Anisian (Virglorian)
Scythian (Werfenian)
Choristoceras marshi
Sirenites argonautae
Pinacoceras metternichi
Cyrtopleurites bicrenatus
Cladiscites ruber
Sagenites giebeli
Discophyllites patens
Tropites subbullatus
Carnites floridus
Trachyceras aonoides
Trachyceras aon
Protrachyceras archelaus
Protrachyceras reitzi
Paraceratites trinodosus
Paraceratites binodosus
Nicomedites osmani
Neopopanoceras haugi
Prohungarites similis
Columbites parisianus
Tirolites cassianus
Anasibirites multiformis
Meekoceras gracilitate
Flemingites flemingianus
"Meekoceras" zone
Koninckites volutus
Xenodiscoides follax
Prionolobus rotundatus
Proptychites rosenkrantzi
Vishnuites decipiens
Ophiceras commune
Otoceras woodwardi
Muschelkalk (Calcaire conchylien)
Bunter or Buntsandstein (Grès bigarré)
1 Tegucigalpa formation
2 Todos Santos formation
3 Mixtepec-El Consuelo beds
4 Cualac quartzite
5 Basal section of clastics and clays
6 Matzitzi formation
7 Huayacocotla formation
Slates, clays, and conglomerates, with coal and fossil plants
Underlying rocks
Paleozoic (?)
Permian
Precambrian
Precambrian
References to bibliography
161,233,253,254, 288,294,375
3,24,86,251, 286,294,342
118,284
2,3,38
2,13,36,78,139 141

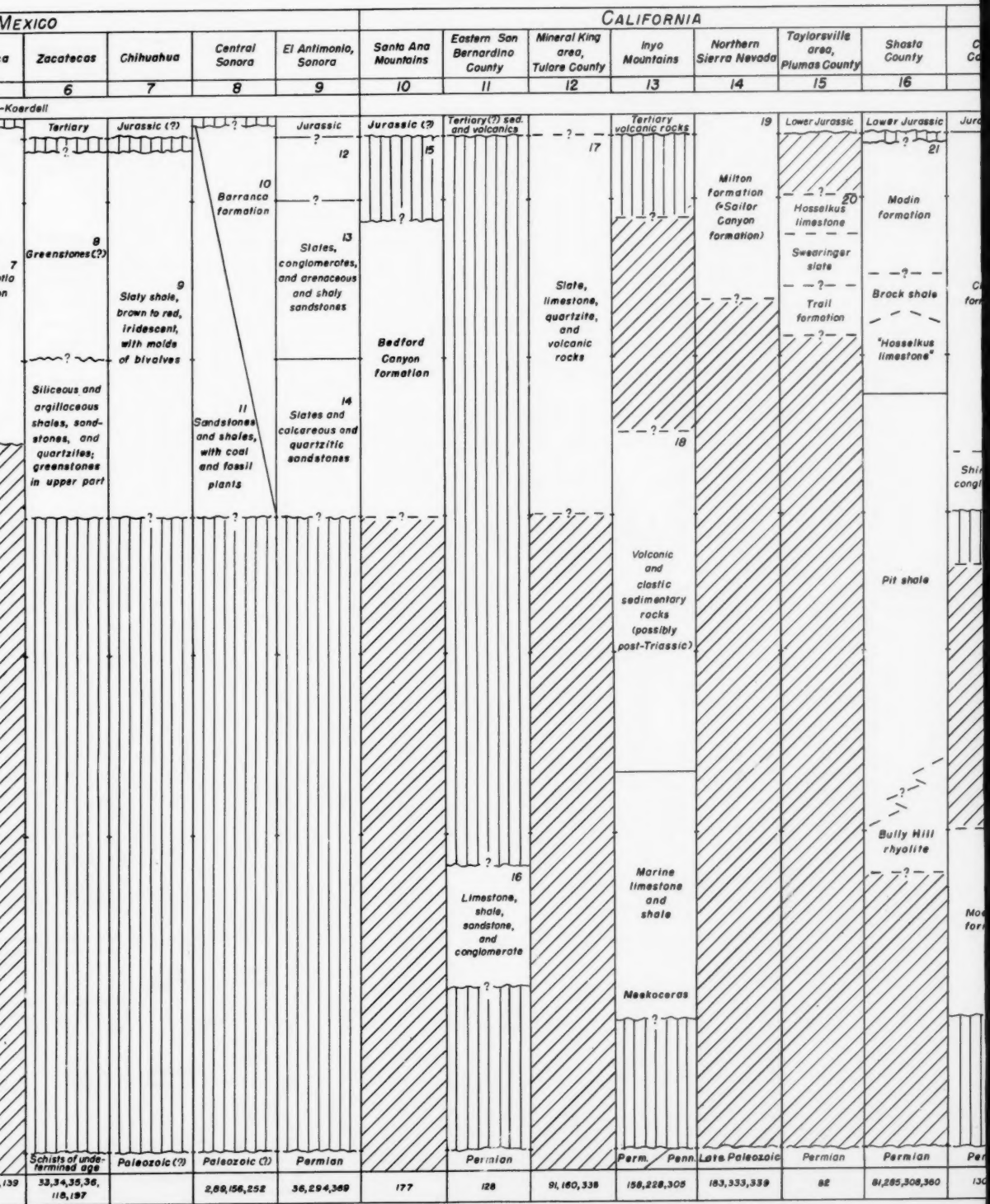
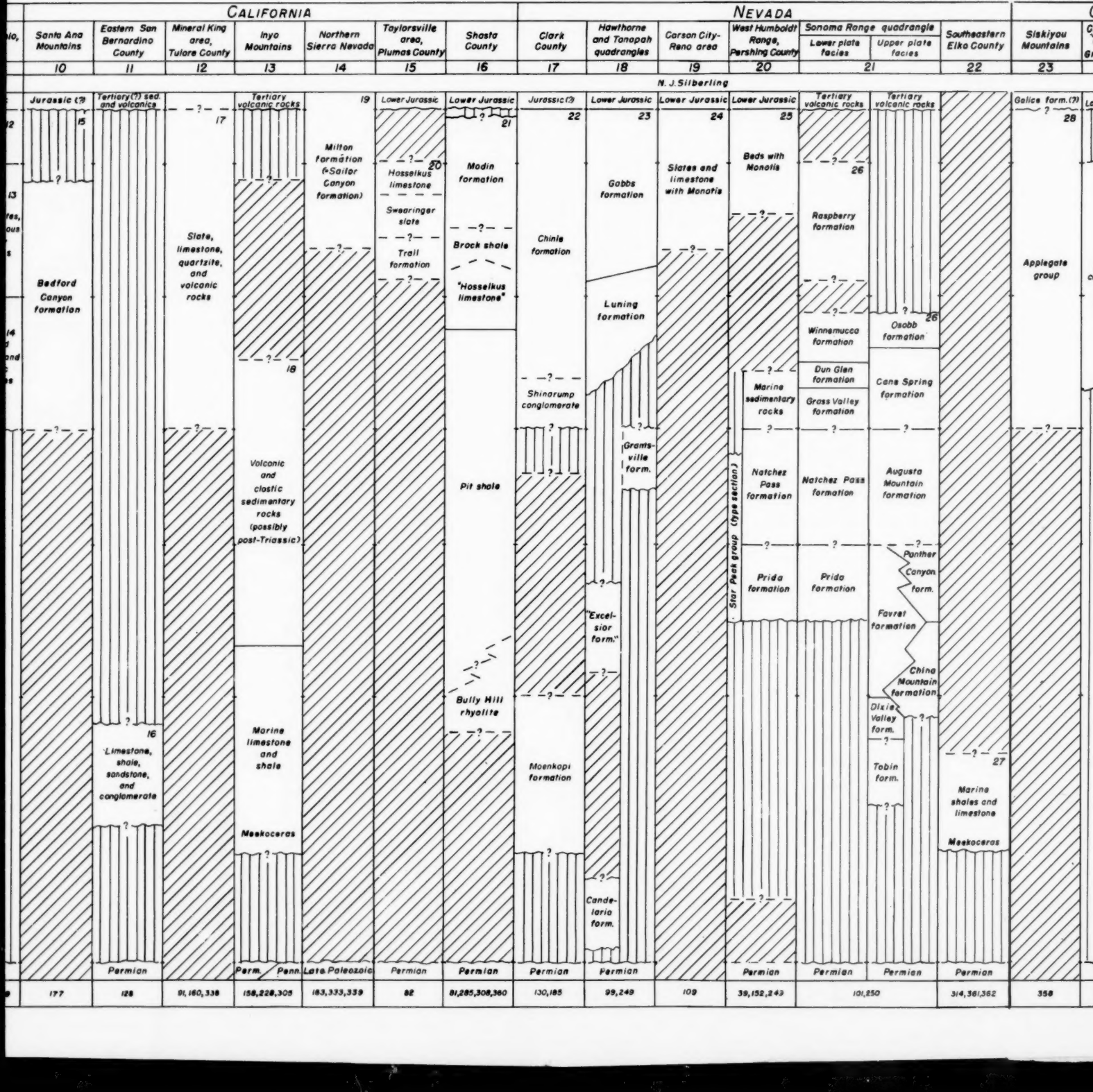

MEXICO
CALIFORNIA
Zacatecas
Chihuahua
Central Sonora
El Antimonio, Sonora
Santa Ana Mountains
Eastern San Bernardino County
Mineral King area, Tulare County
Inyo Mountains
Northern Sierra Nevada
Taylorsville area, Plumas County
Shasta County
6
7
8
9
10
11
12
13
14
15
16
-Koerdell
Tertiary
Jurassic (?)
Jurassic
Jurassic (?)
Tertiary(?) sed. and volcanics
Tertiary volcanic rocks
Lower Jurassic
Lower Jurassic
8 Greenstones(?)
Siliceous and argillaceous shales, sandstones, and quartzites; greenstones in upper part
9 Slaty shale, brown to red, iridescent, with molds of bivalves
10 Barranca formation
11 Sandstones and shales, with coal and fossil plants
12
13 Slates, conglomerates, and arenaceous and shaly sandstones
14 Slates and calcareous and quartzitic sandstones
15 Bedford Canyon formation
16 Limestone, shale, sandstone, and conglomerate
17 Slate, limestone, quartzite, and volcanic rocks
18 Volcanic and clastic sedimentary rocks (possibly post-Triassic)
Marine limestone and shale
Meekoceras
19 Milton formation (=Sailor Canyon formation)
20 Hosselkus limestone
Swearinger slate
Trail formation
21 Modin formation
Brock shale
"Hosselkus limestone"
Pit shale
Bully Hill rhyolite
Schists of undetermined age
Paleozoic (?)
Paleozoic (?)
Permian
Permian
Perm. Penn.
Late Paleozoic
Permian
Permian
33,34,35,36, 118,197
2,89,156,252
36,294,369
177
128
91, 160, 338
158,228,305
183,333,339
82
81,285,308,360

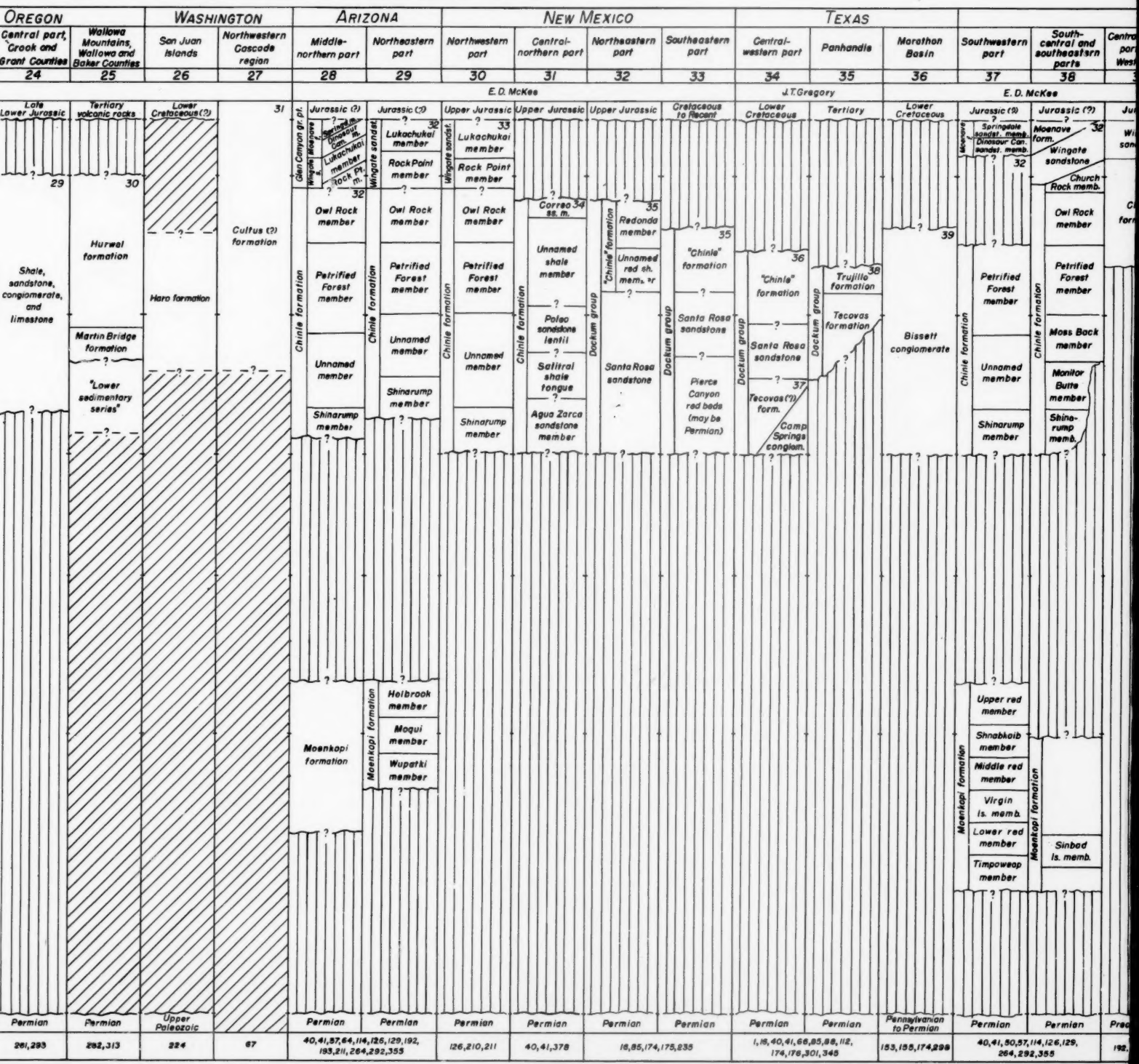
Chart 8a. - CORRELATION OF TRIASSIC FORMATION

By the Triassic Subcommittee, John B. Reeside, Jr. (Chairman), P. L. Applin,
J. D. Love, Manuel Maldonado-Koerdell, E. D. McKee, D. B. McLaughlin, S. W.

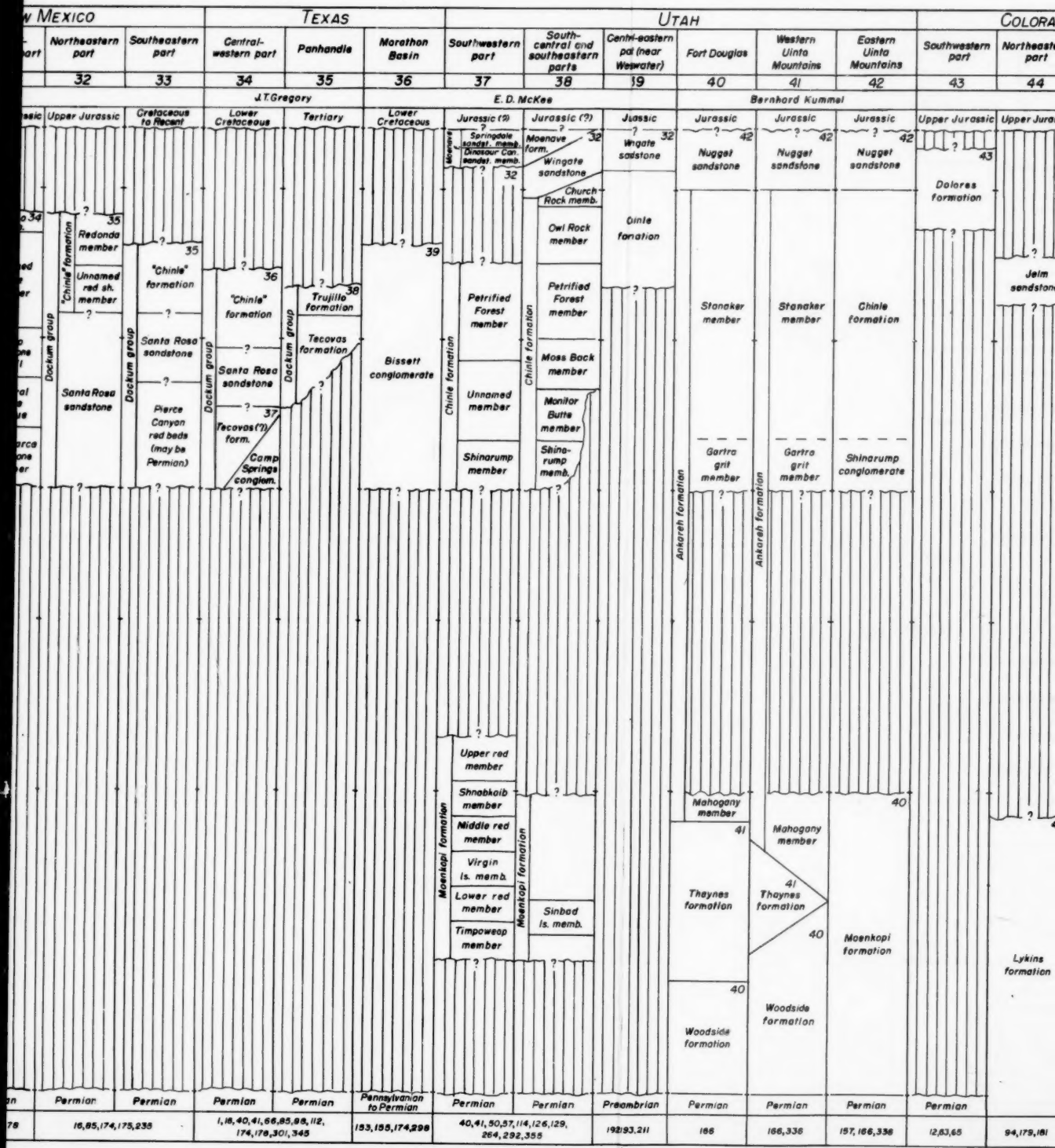


ONS OF NORTH AMERICA EXCLUSIVE OF CANADA

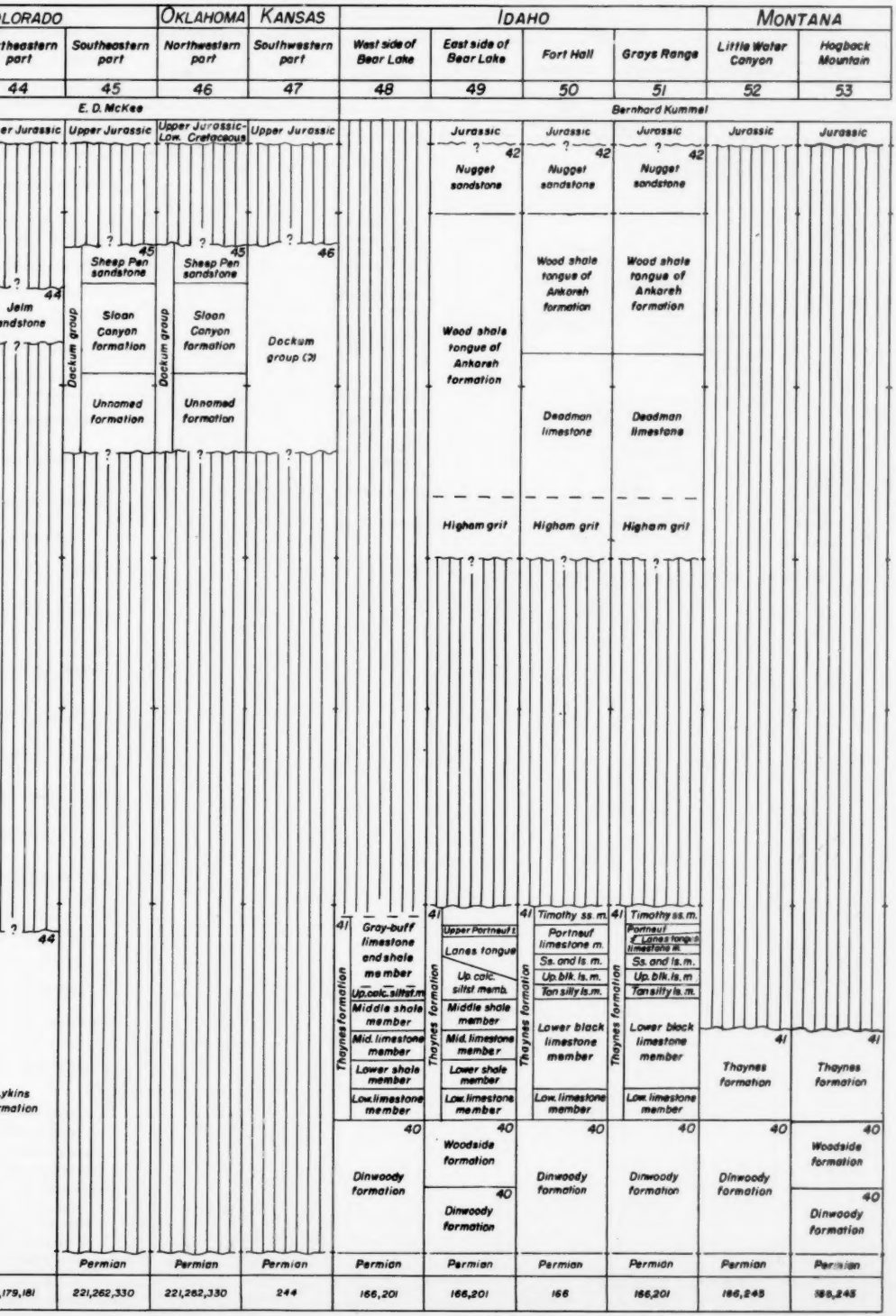
plin, E. H. Colbert, J. T. Gregory, H. D. Hadley, Bernhard Kummel, P. J. Lewis,
S. W. Muller, J. A. Reinemund, John Rodgers, N. J. Silberling and Karl Waage

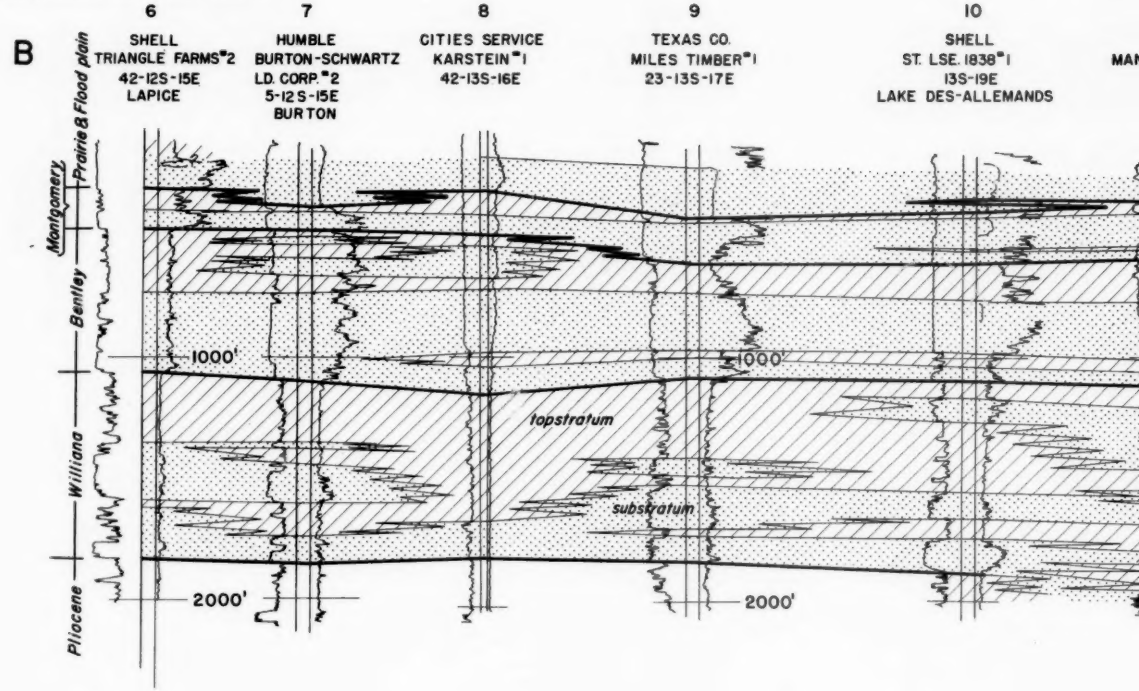


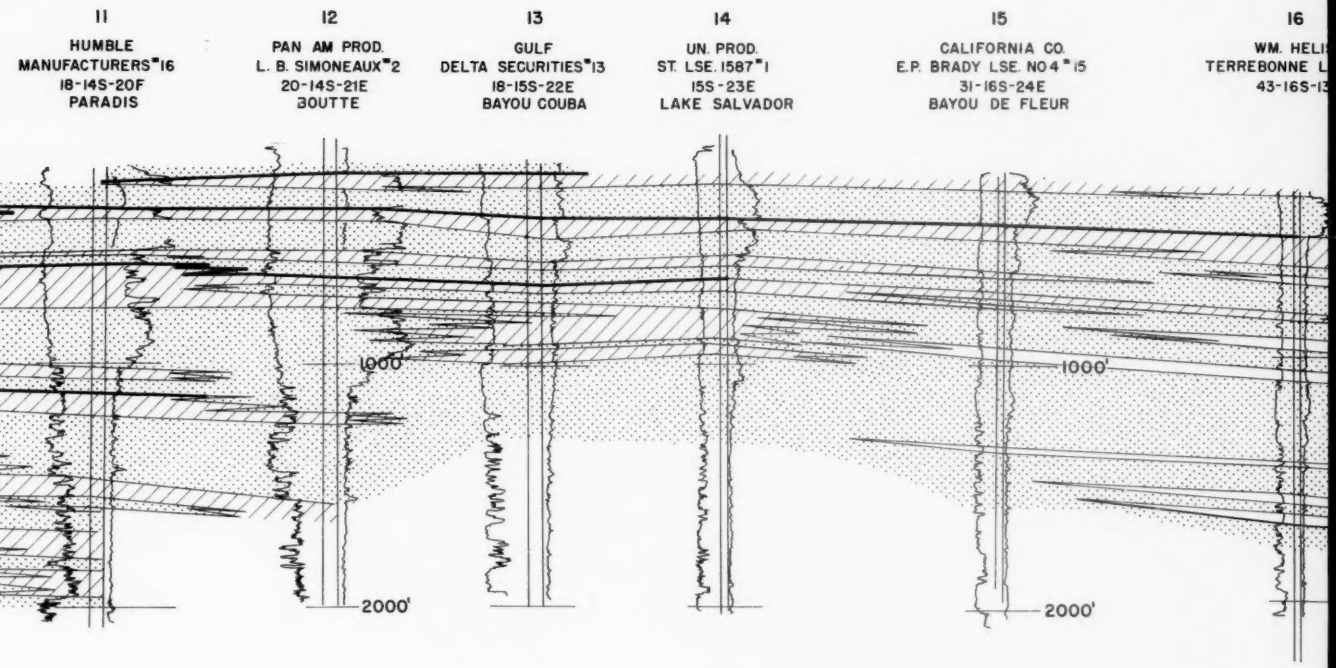
CANADA


w Mexico
Texas
Utah
Colora
Northeastern part
Southeastern part
Central-western part
Panhandle
Marathon Basin
Southwestern part
South-central and southeastern parts
Centri-eastern pa (near Wasatch)
Fort Douglas
Western Uinta Mountains
Eastern Uinta Mountains
Southwestern part
Northeast part
32
33
34
35
36
37
38
39
40
41
42
43
44
J.T.Gregory
E. D. McKee
Bernhard Kummel
Upper Jurassic
Cretaceous to Recent
Lower Cretaceous
Tertiary
Lower Cretaceous
Jurassic (?)
Jurassic (?)
Jurassic
Jurassic
Jurassic
Jurassic
Upper Jurassic
Upper Jura
Redonda member
"Chinle" formation
Unnamed red sh. member
Santa Rosa sandstone
Dockum group
"Chinle" formation
Santa Rosa sandstone
Pierce Canyon red beds (may be Permian)
"Chinle" formation
Santa Rosa sandstone
Tecovas (?) form.
Camp Springs congiom.
Trujillo formation
Tecovas formation
Bissett conglomerate
Moenave
Springdale sandst. memb.
Dinosaur Can. sandst. memb.
Petrified Forest member
Unnamed member
Shinarump member
Chinle formation
Upper red member
Shnabkaib member
Middle red member
Virgin ls. memb.
Lower red member
Timpoweap member
Moenkopi formation
Moenave form.
Wingate sandstone
Church Rock memb.
Owl Rock member
Petrified Forest member
Moss Back member
Monitor Butte member
Shinarump memb.
Chinle formation
Sinbad ls. memb.
Moenkopi formation
Wingate sandstone
Chinle formation
Nugget sandstone
Stanaker member
Gartra grit member
Ankareh formation
Mahogany member
Thaynes formation
Woodside formation
Nugget sandstone
Stanaker member
Gartra grit member
Ankareh formation
Mahogany member
Thaynes formation
Woodside formation
Nugget sandstone
Chinle formation
Shinarump conglomerate
Moenkopi formation
Dolores formation
Jelm sandstone
Lykins formation
Permian
Permian
Permian
Permian
Pennsylvanian to Permian
Permian
Permian
Precambrian
Permian
Permian
Permian
Permian
16,85,174,175,235
1,18,40,41,66,85,98,112,174,178,301,345
153,155,174,298
40,41,50,57,114,126,129,264,292,355
192193,211
166
166,336
157,166,336
12,83,65
94,179,181

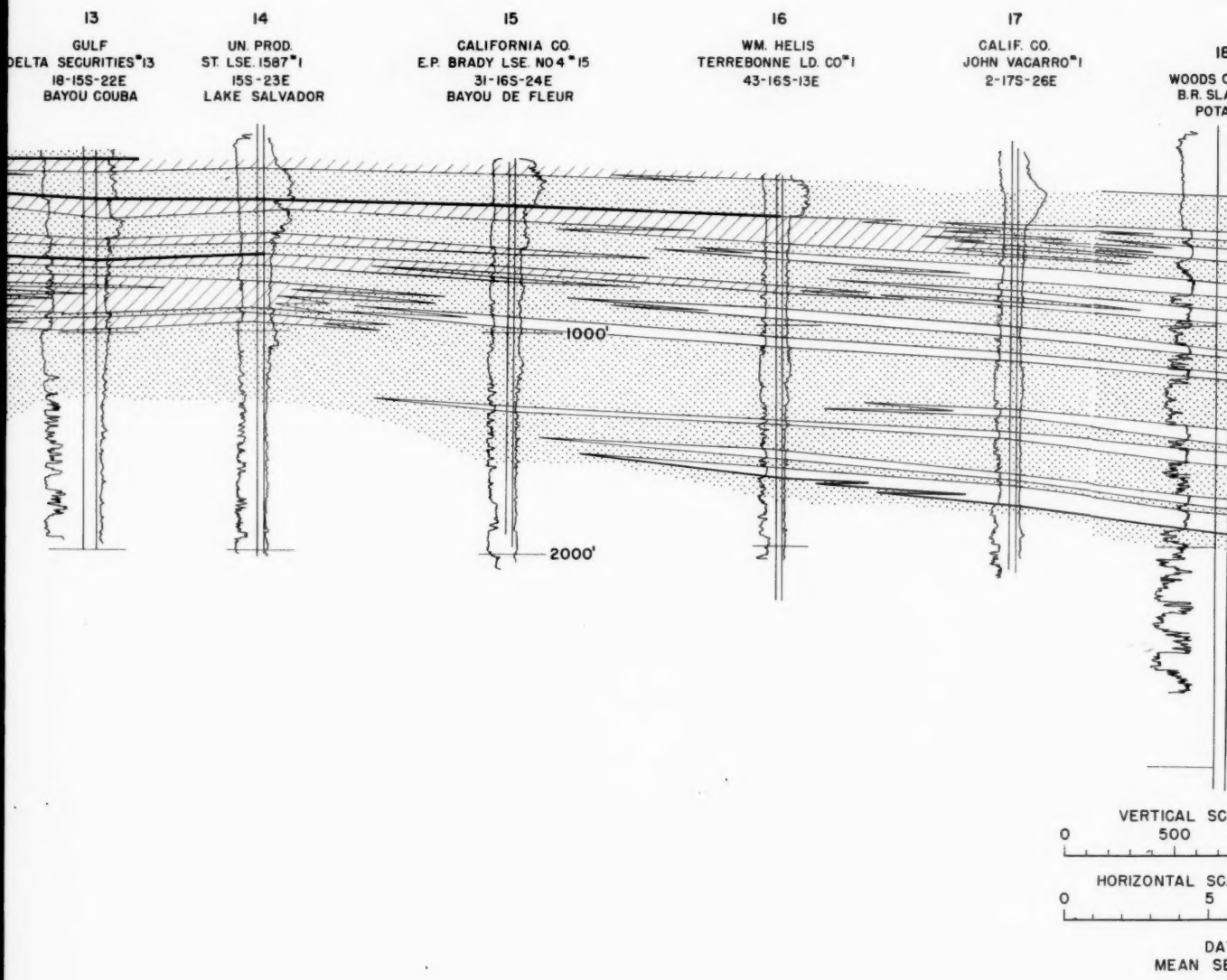
Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*



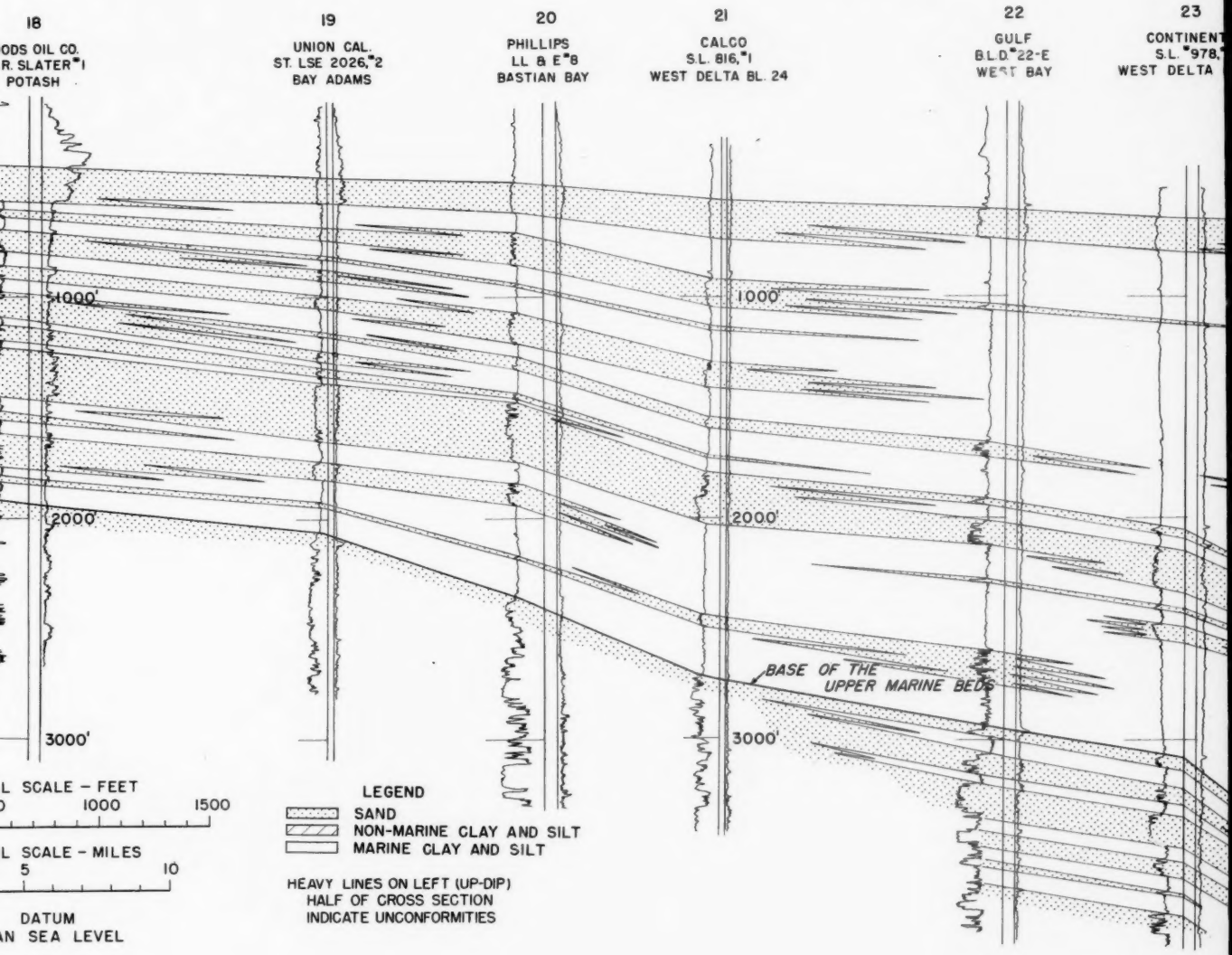

B
6
SHELL
TRIANGLE FARMS #2
42-12S-15E
LAPICE
7
HUMBLE
BURTON-SCHWARTZ
LD. CORP. #2
5-12S-15E
BURTON
8
CITIES SERVICE
KARSTEIN #1
42-13S-16E
9
TEXAS CO.
MILES TIMBER #1
23-13S-17E
10
SHELL
ST. LSE. 1838 #1
13S-19E
LAKE DES-ALLEMANDS
Prairie & Flood plain
Montgomery
Bentley
Williana
Pliocene
1000'
2000'
topstratum
substratum



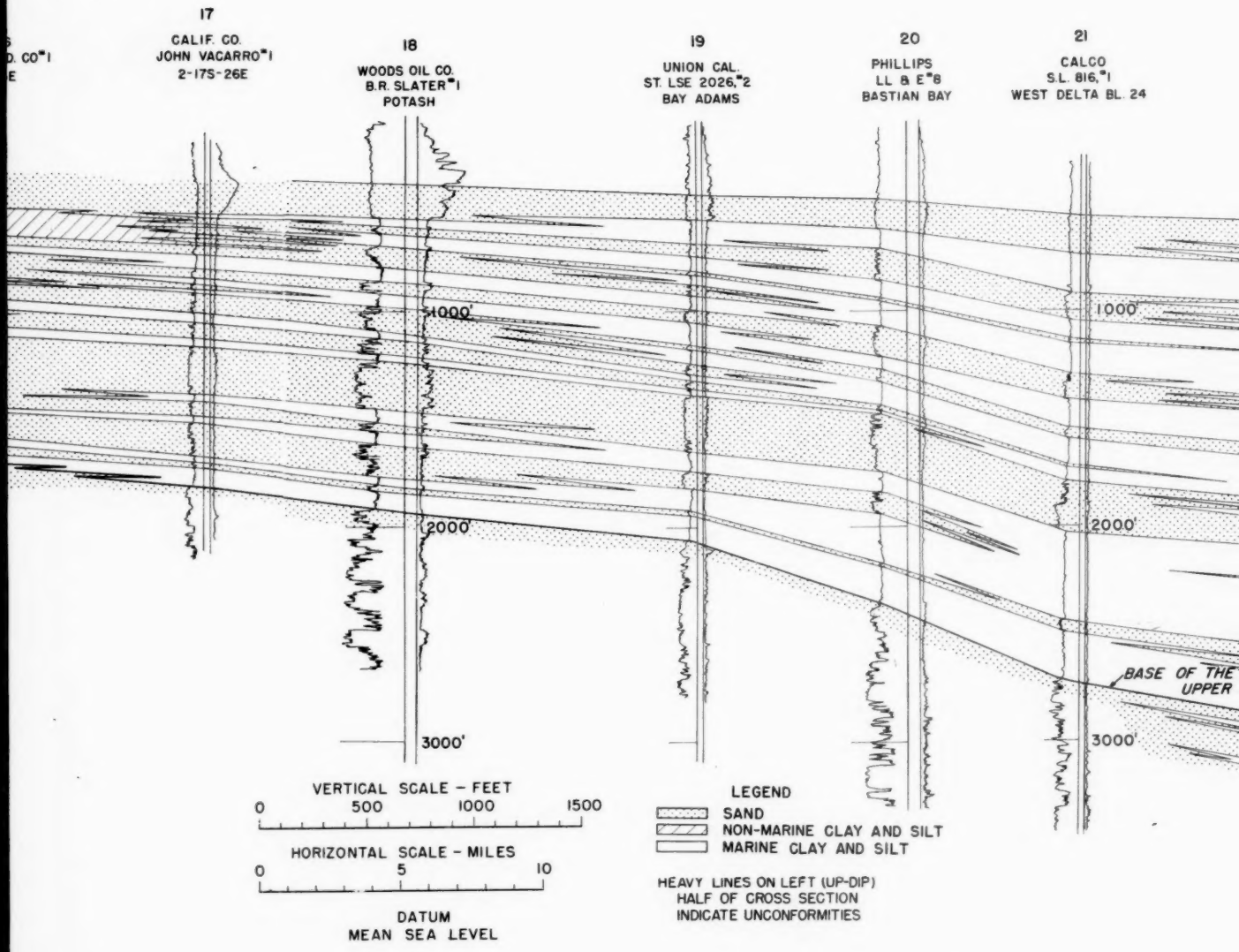
CROSS SECTION B-C LAPICE FIELD T



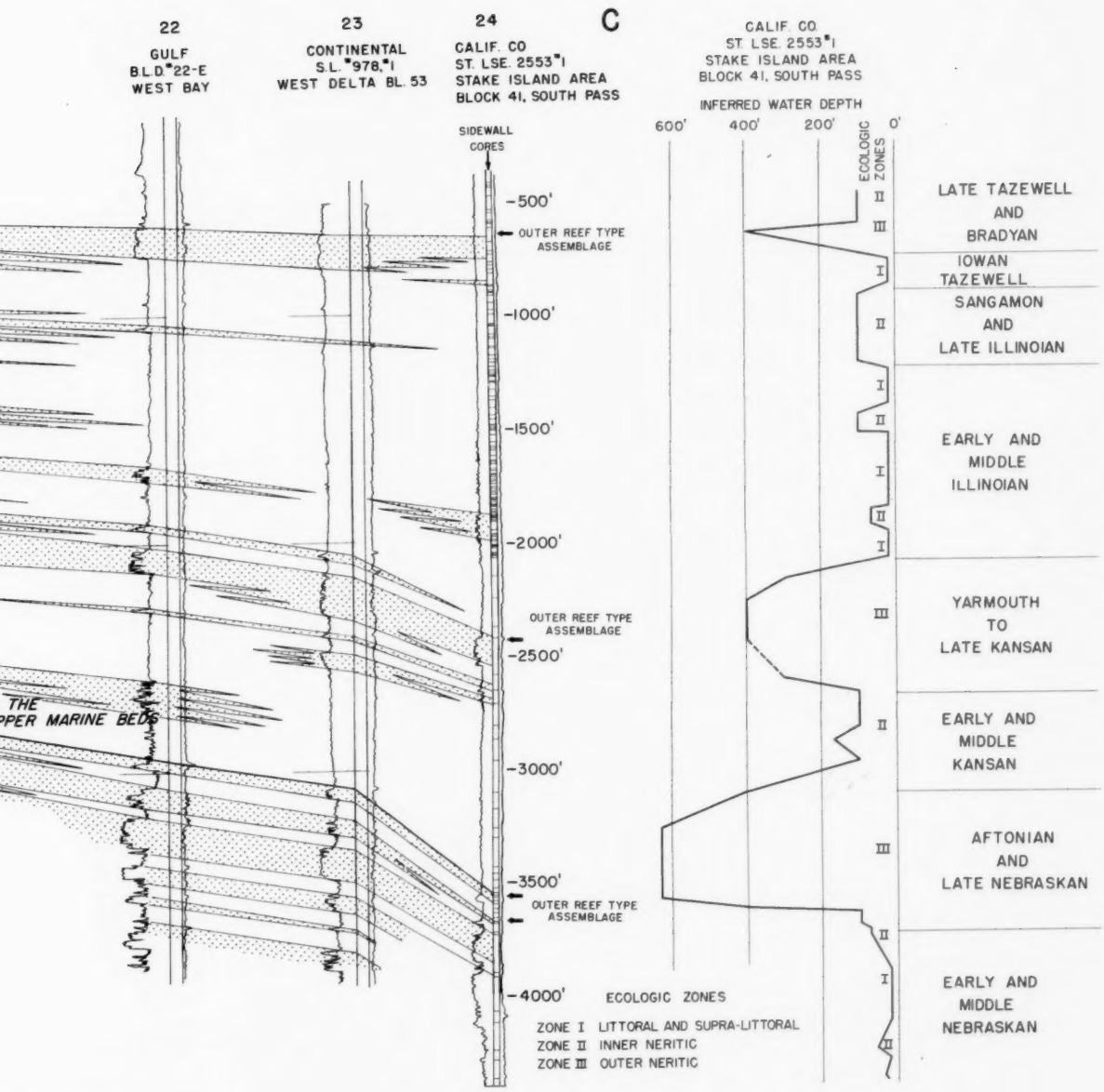
CROSS SECTION B-C LAPICE FIELD TO SOUTH PASS, BLOCK 41 FI

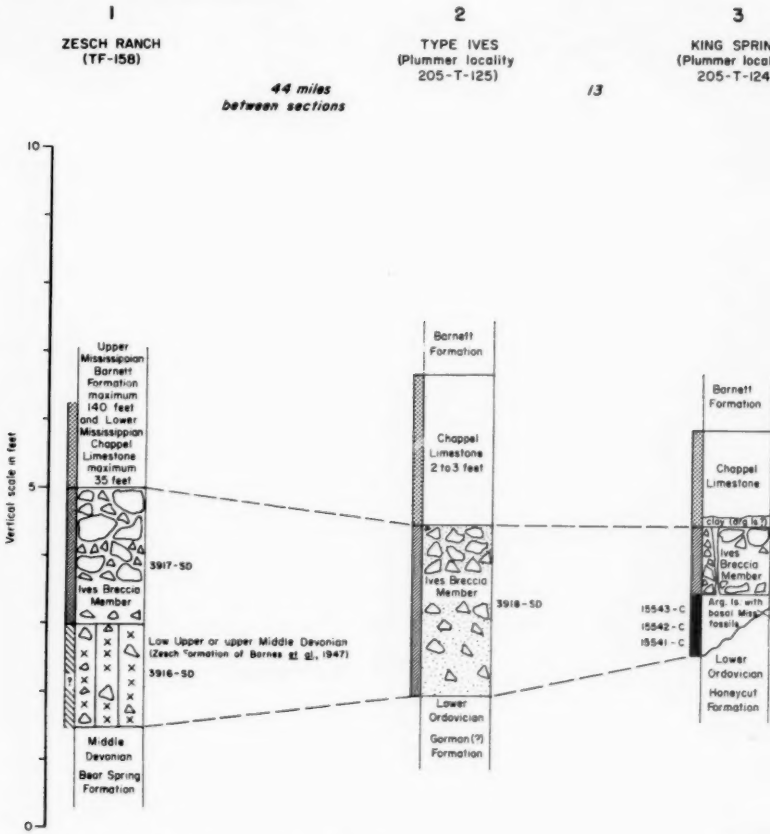


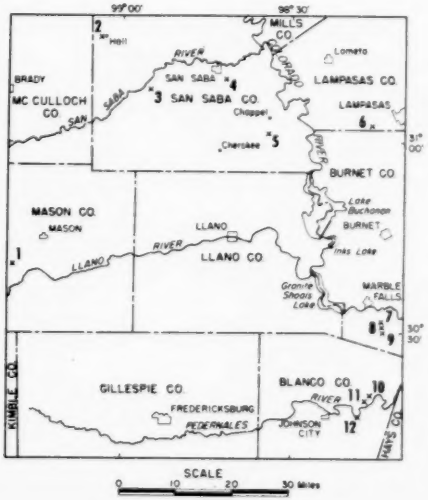
1 FIELD, LOUISIANA

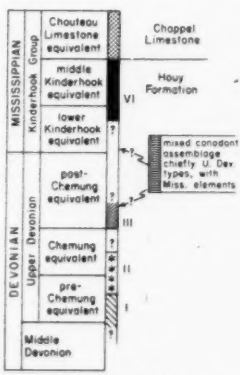


TO SOUTH PASS, BLOCK 41 FIELD, LOUISIANA

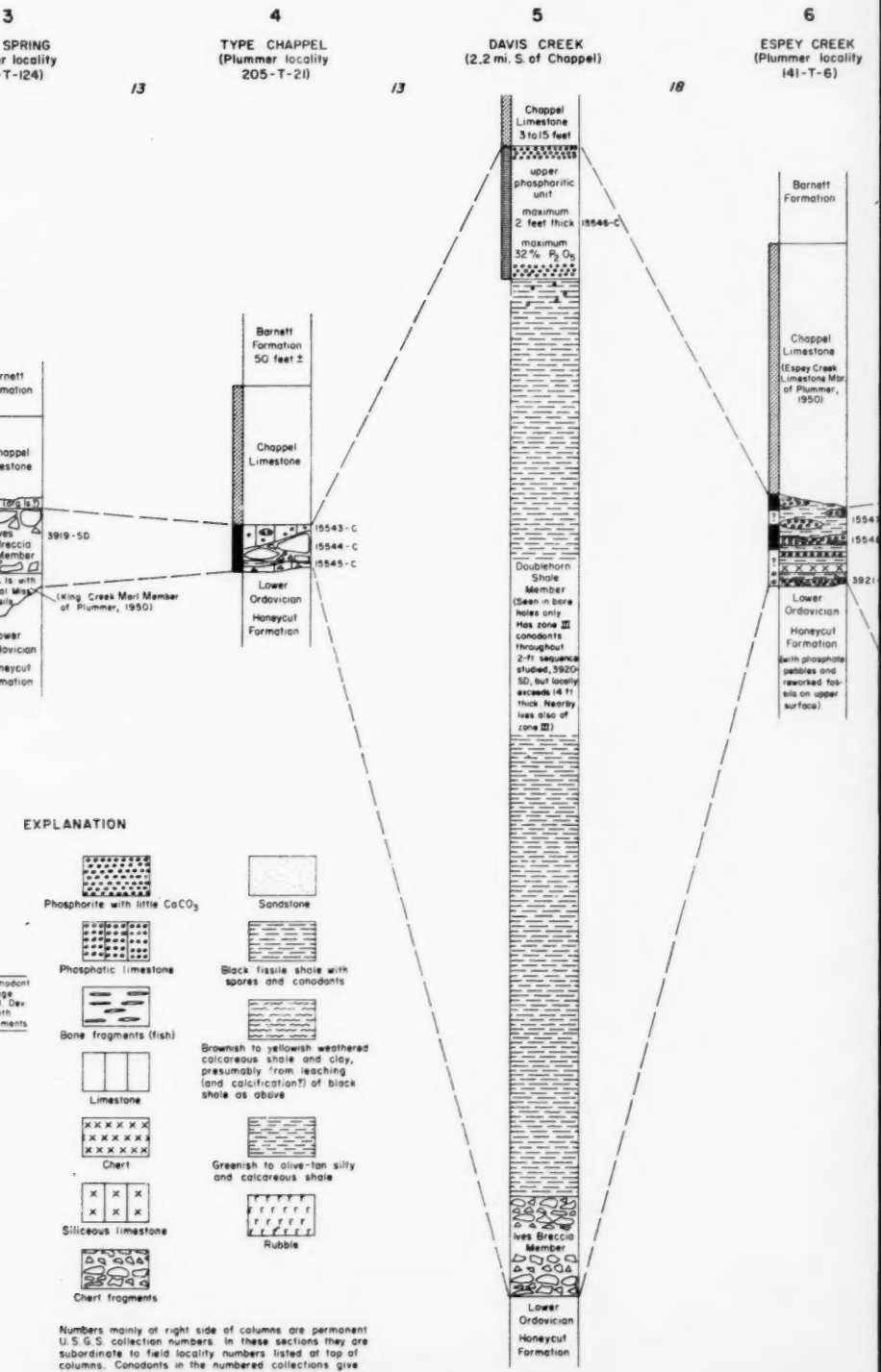

22
GULF
B.L.D."22-E
WEST BAY
23
CONTINENTAL
S.L. "978,"1
WEST DELTA BL. 53
24
CALIF. CO
ST. LSE. 2553"1
STAKE ISLAND AREA
BLOCK 41, SOUTH PASS
C
SIDEWALL CORES
-500'
OUTER REEF TYPE ASSEMBLAGE
-1000'
-1500'
-2000'
OUTER REEF TYPE ASSEMBLAGE
-2500'
THE
PPER MARINE BEDS
-3000'
-3500'
OUTER REEF TYPE ASSEMBLAGE
-4000'
CALIF. CO
ST. LSE. 2553"1
STAKE ISLAND AREA
BLOCK 41, SOUTH PASS
INFERRED WATER DEPTH
600'
400'
200'
0'
ECOLOGIC ZONES
LATE TAZEWELL AND BRADYAN
IOWAN TAZEWELL
SANGAMON AND LATE ILLINOIAN
EARLY AND MIDDLE ILLINOIAN
YARMOUTH TO LATE KANSAN
EARLY AND MIDDLE KANSAN
AFTONIAN AND LATE NEBRASKAN
EARLY AND MIDDLE NEBRASKAN
ECOLOGIC ZONES
ZONE I LITTORAL AND SUPRA-LITTORAL
ZONE II INNER NERITIC
ZONE III OUTER NERITIC





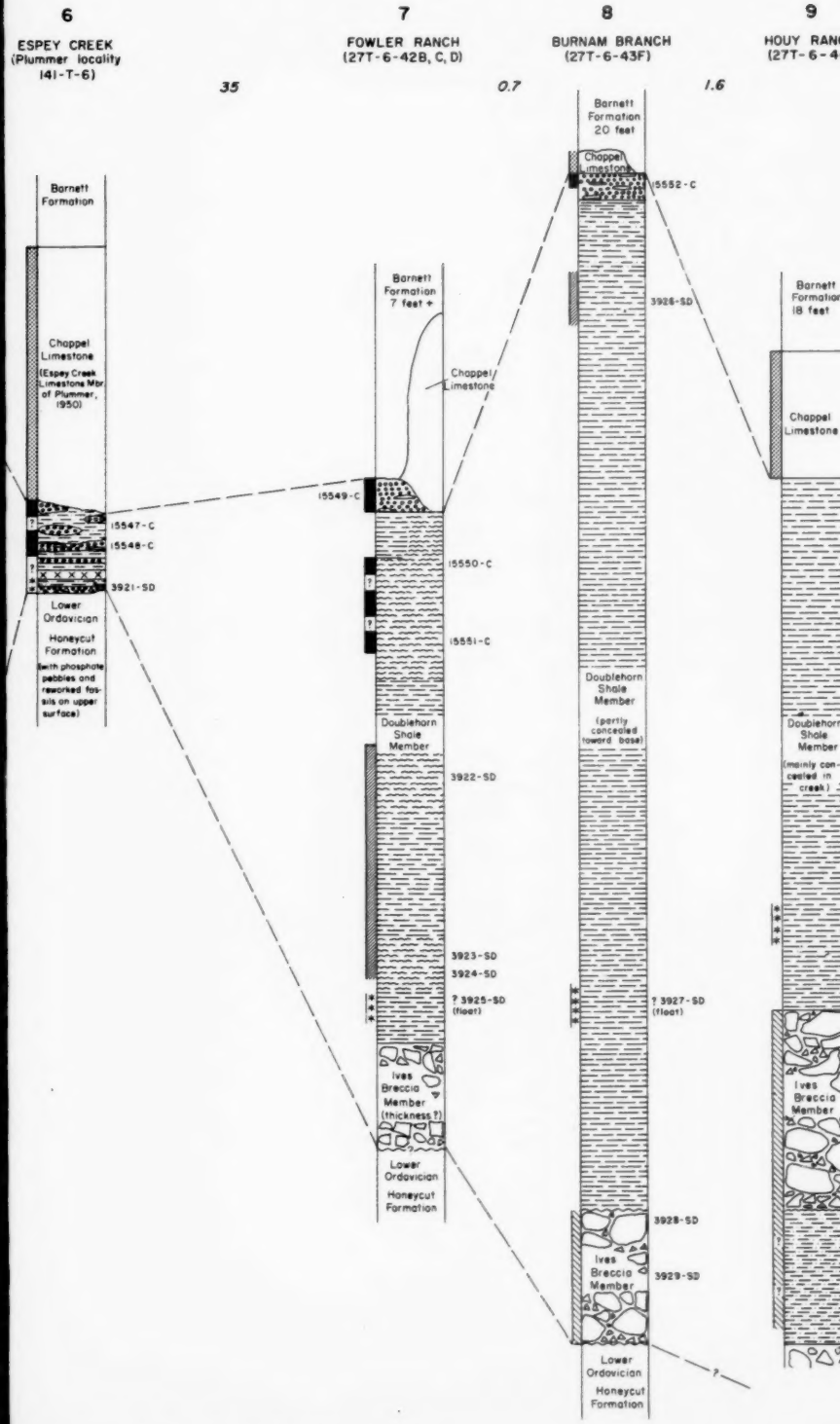


Faunal equivalence of Houy Formation and capping beds of Early Mississippian age

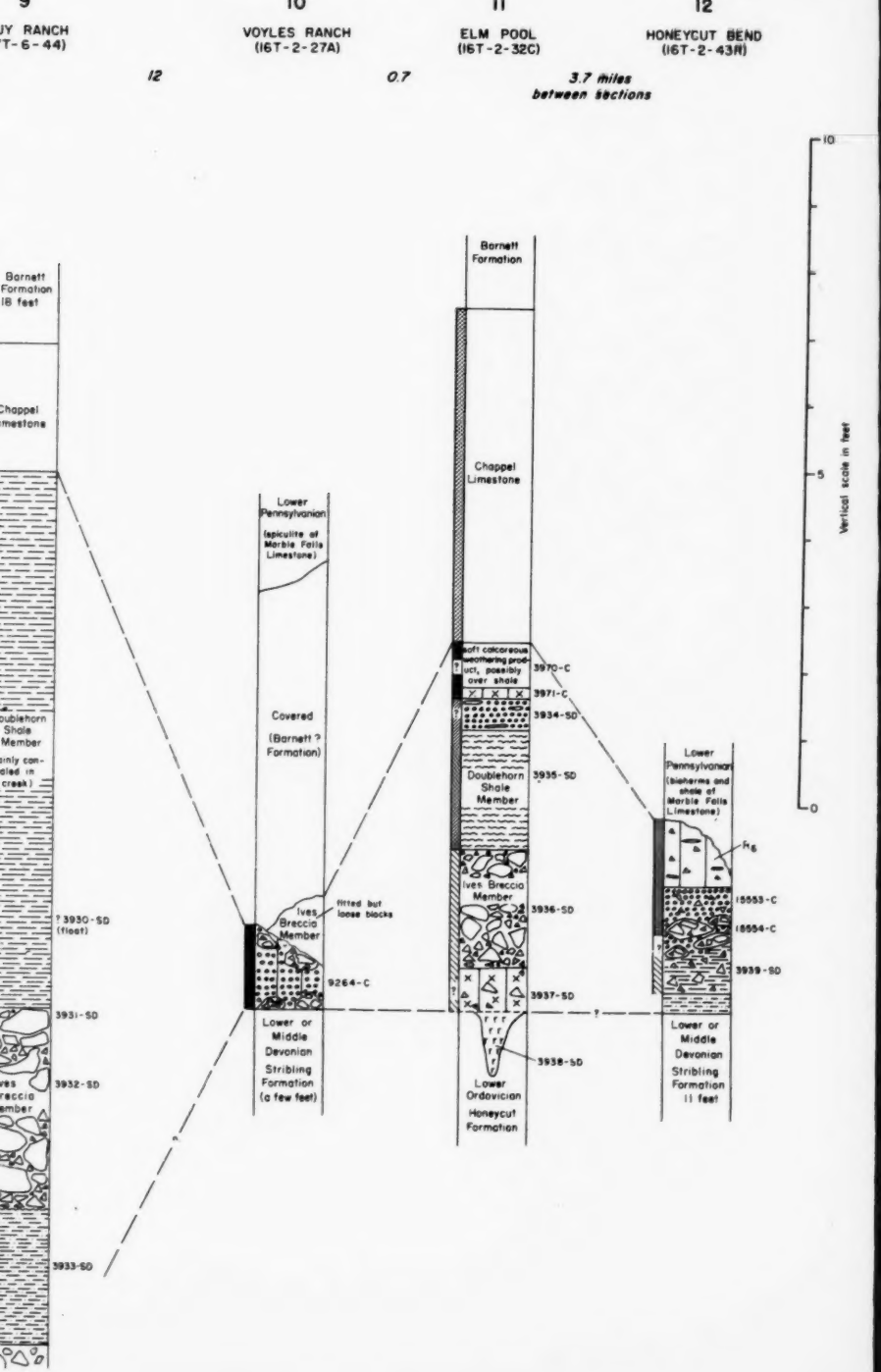


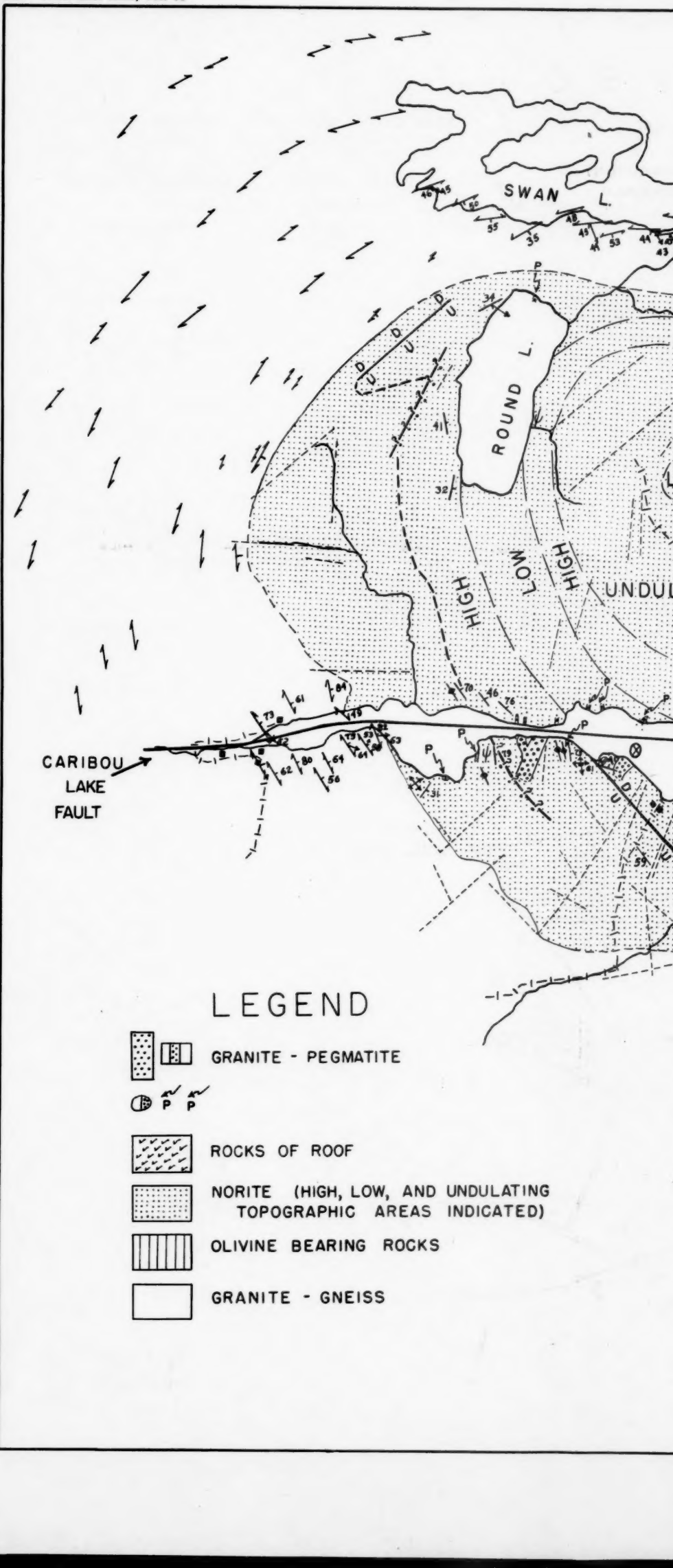
Numbers mainly at right side of columns are permanent U.S.G.S. collection numbers. In these sections they are subordinate to field locality numbers listed at top of columns. Conodonts in the numbered collections give principal basis for correlations within Houy Formation

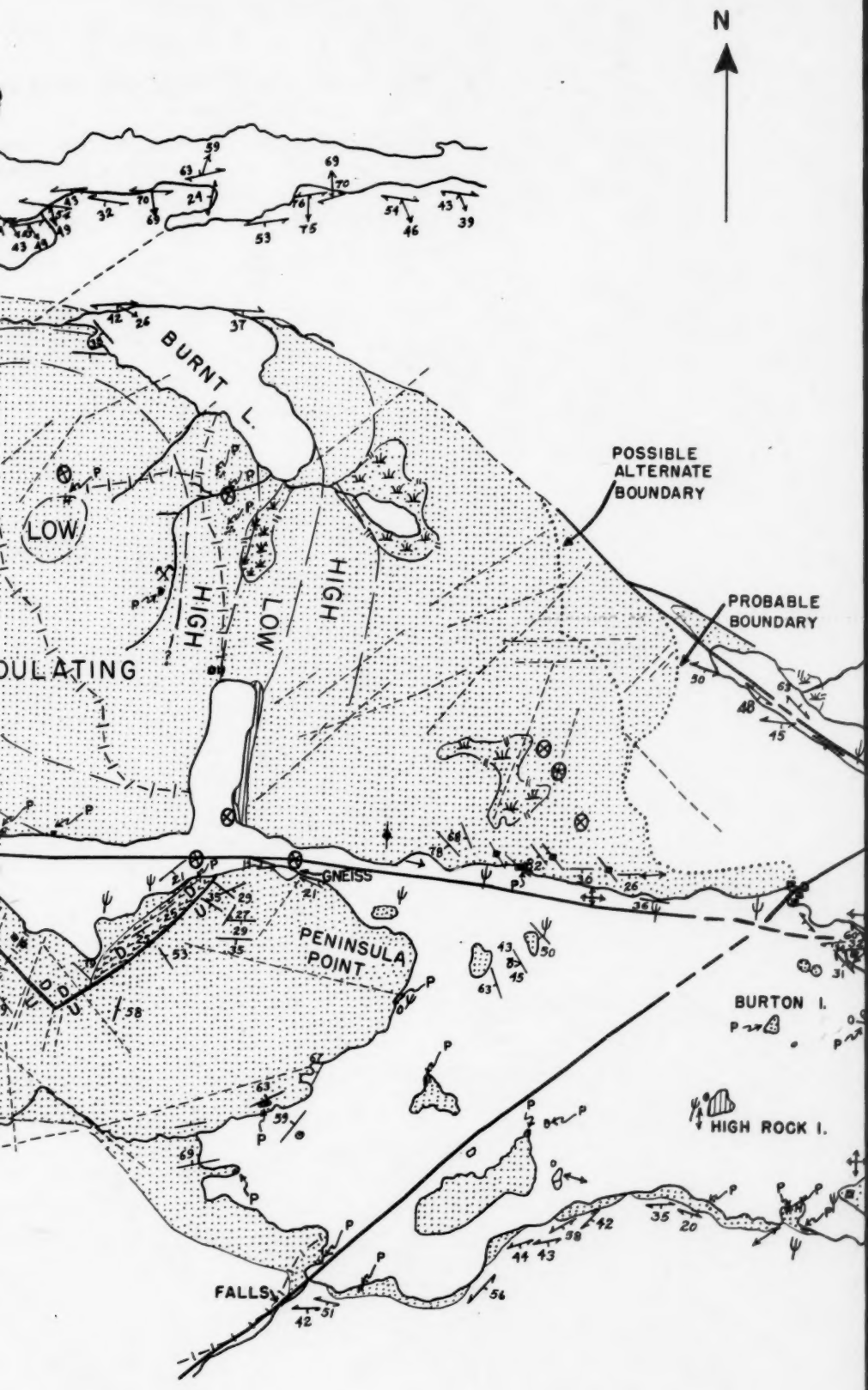
KEY SECTIONS OF THE E



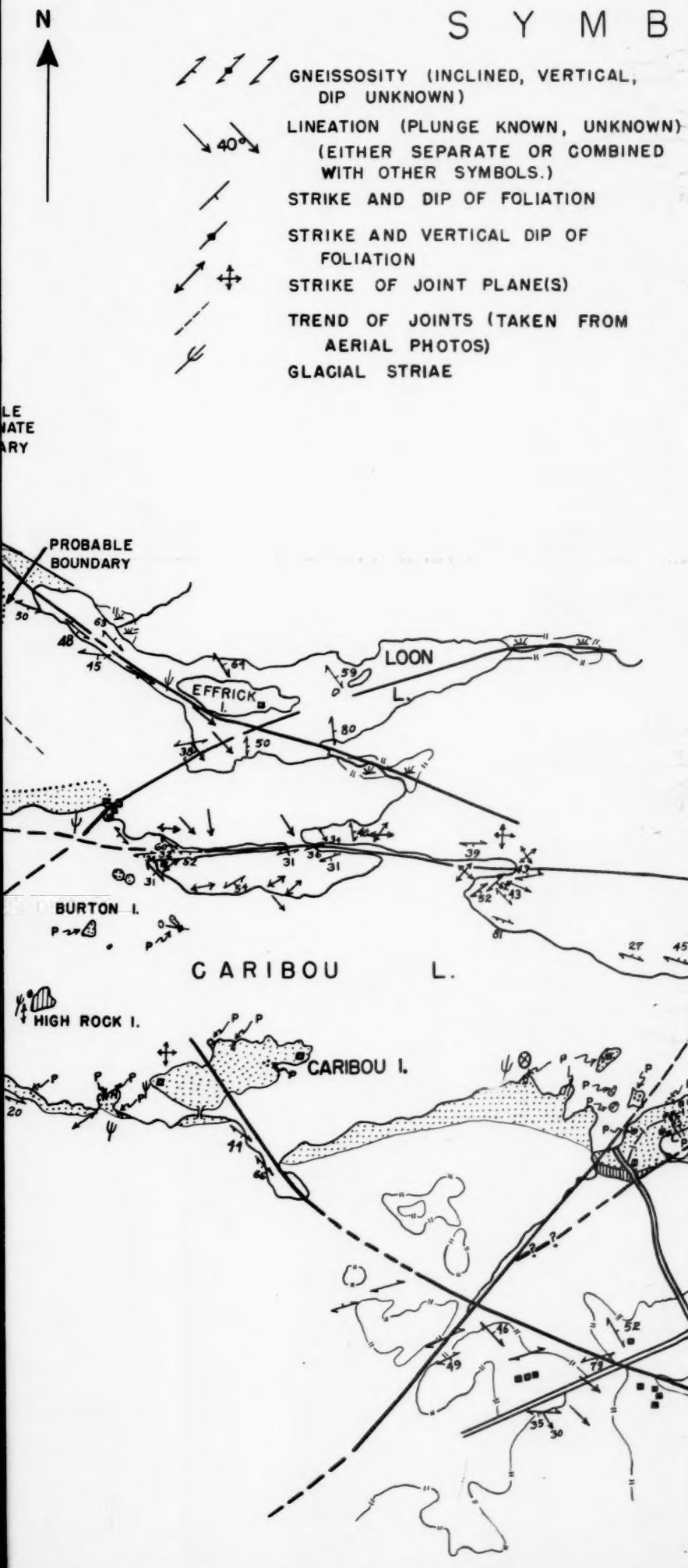
F THE HOUY FORMATION


9
JY RANCH
T-6-44)
10
VOYLES RANCH
(16T-2-27A)
11
ELM POOL
(16T-2-32C)
12
HONEYCUT BEND
(16T-2-43H)
12
0.7
3.7 miles
between sections
Barnett
Formation
18 feet
Chappel
imestone
oublehorn
Shale
Member
inly con-
ded in
creek)
? 3930-SD
(float)
3931-SD
ves
reccia
mber
3932-SD
3933-SD
Barnett
Formation
Chappel
Limestone
Lower
Pennsylvanian
(spiculite of
Marble Falls
Limestone)
Covered
(Barnett ?
Formation)
Ives
Breccia
Member
fitted but
loose blocks
9264-C
Lower or
Middle
Devonian
Stribling
Formation
(a few feet)
soft calcareous
weathering prod-
uct, possibly
over shale
3970-C
3971-C
3934-SD
Doublehorn
Shale
Member
3935-SD
Ives Breccia
Member
3936-SD
3937-SD
3938-SD
Lower
Ordovician
Honeycut
Formation
Lower
Pennsylvanian
(biohermes and
shale of
Marble Falls
Limestone)
P_6
18553-C
18554-C
3939-SD
Lower or
Middle
Devonian
Stribling
Formation
11 feet
10
5
0
Vertical scale in feet


SWAN L.
ROUND L.
HIGH
LOW
HIGH
UNDUL
CARIBOU
LAKE
FAULT
LEGEND
GRANITE - PEGMATITE
ROCKS OF ROOF
NORITE (HIGH, LOW, AND UNDULATING TOPOGRAPHIC AREAS INDICATED)
OLIVINE BEARING ROCKS
GRANITE - GNEISS



GEOLOGIC MAP OF CARIBOU LAKE INT



OU LAKE INTRUSIVE BODY

B O L S

GEOLOGICAL BOUNDARY (DEFINED OR OBSERVED, APPROXIMATE, PROBABLE OR POSSIBLE.)

FAULT (POSITION DEFINED, APPROXIMATE, HYPOTHETICAL.)
(U = UPTHROW D = DOWNTHROW)

TRAIL

ROAD

PROSPECT

CLEARING

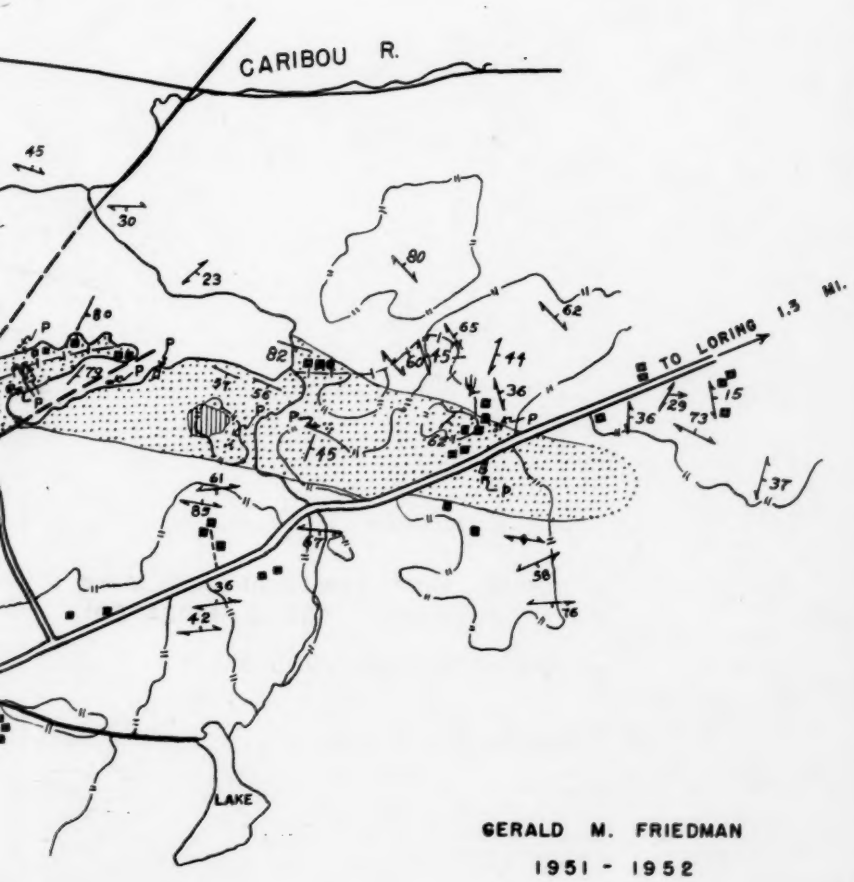
HOUSE

SWAMP

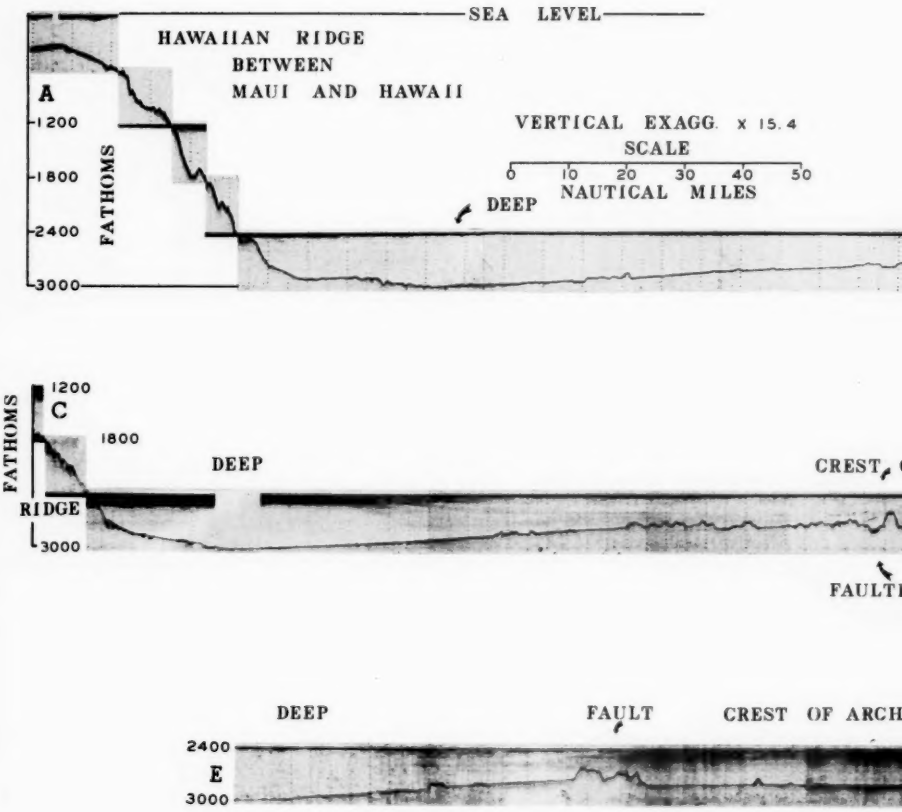
QUARRY

SCALE

0 1/4 1/2 3/4 1 MILE

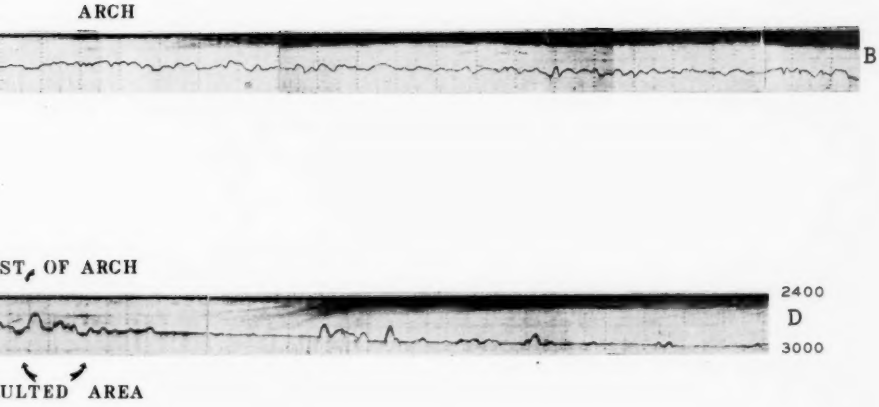


GERALD M. FRIEDMAN
1951 - 1952

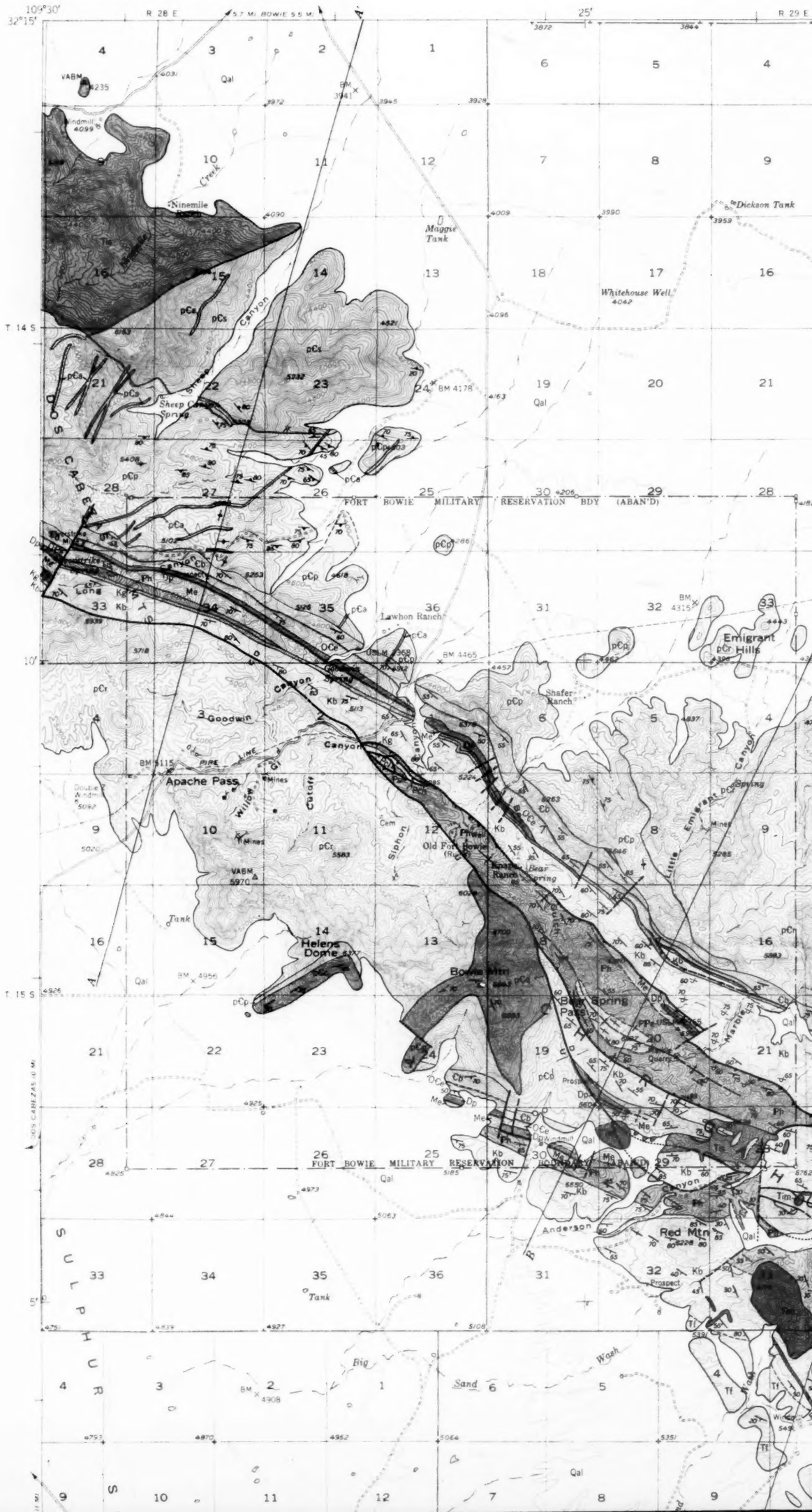


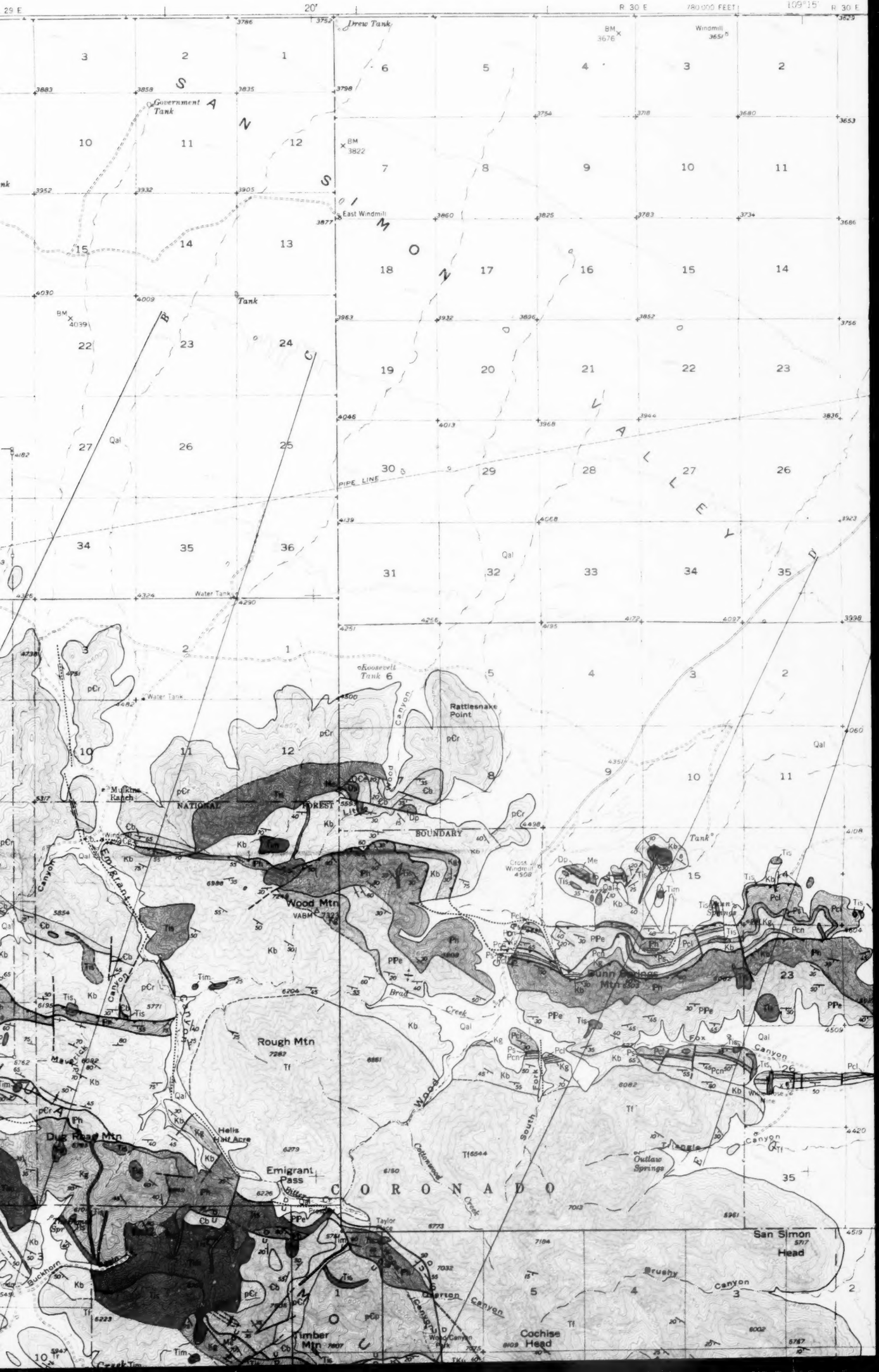
ECHO-SOUNDER RECORDS ACROSS THE

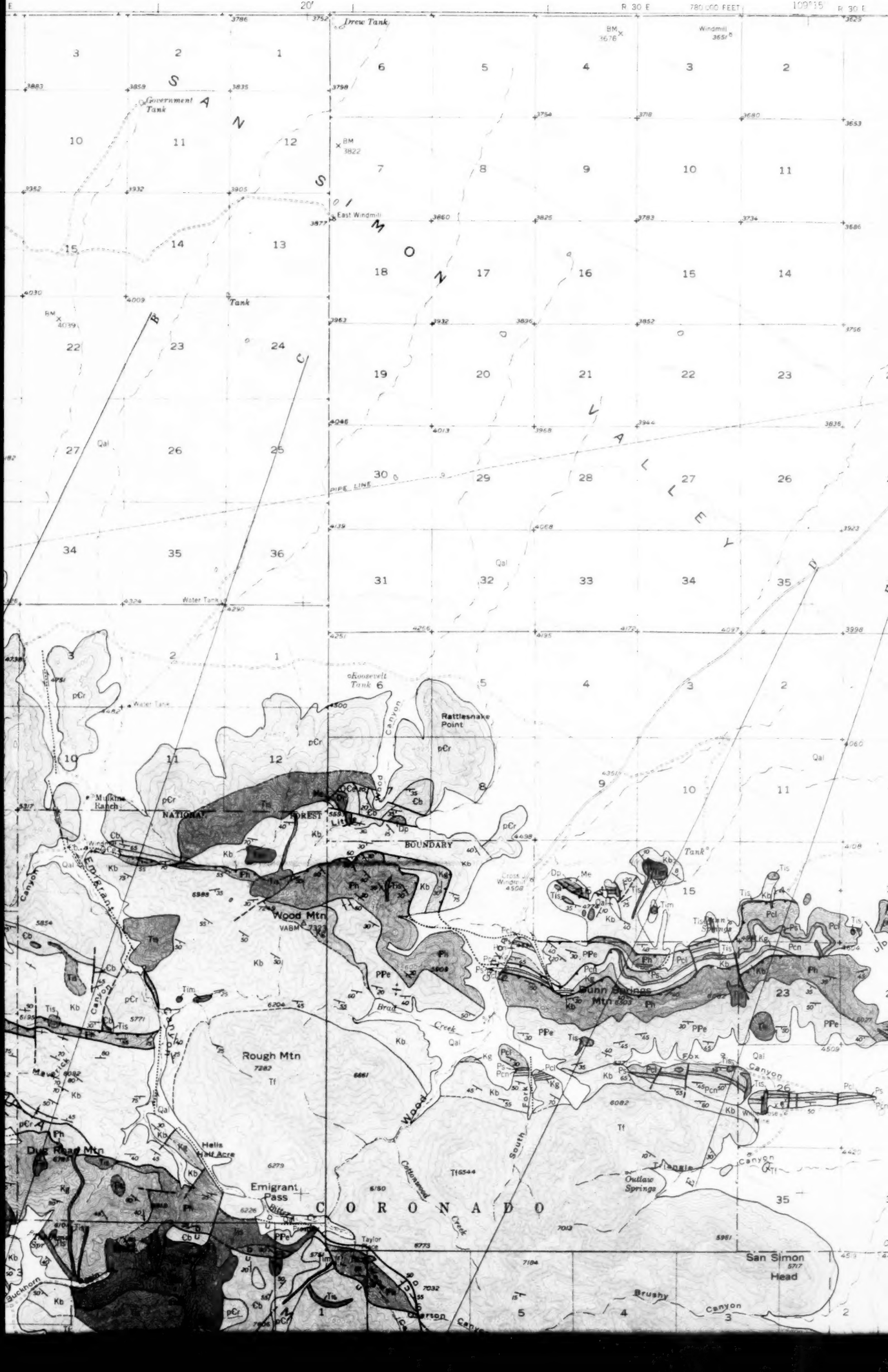
See Figure 1 for the locations of



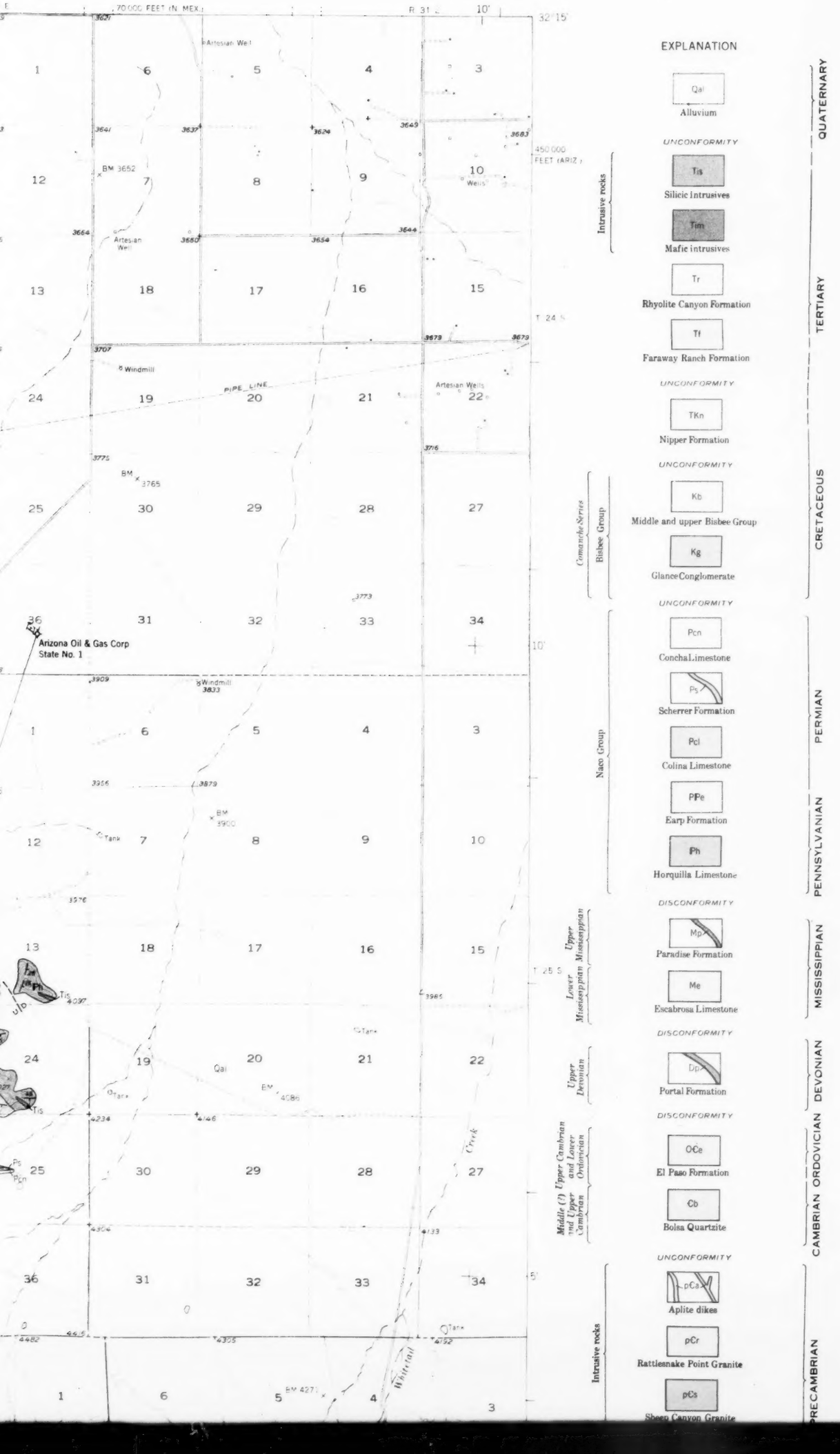
THE HAWAIIAN DEEP AND ARCH
ions of the sounding lines

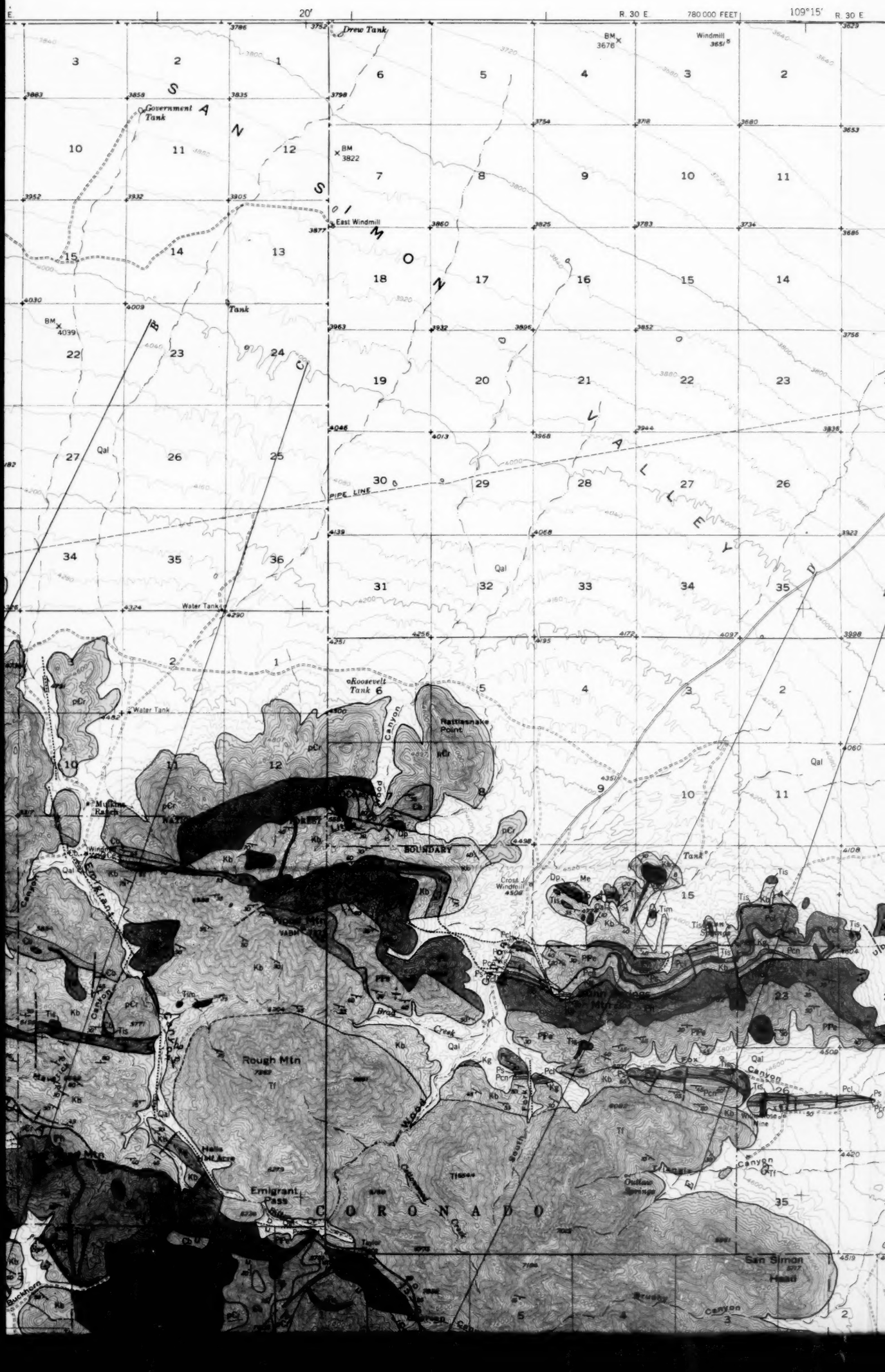

109°30'
32°15'
R 28 E
R 29 E
25'
5.7 MI. BOWIE 5.5 MI.
T 14 S
T 15 S
Ninemile
Maggie Tank
Dickson Tank
Whitehouse Well
Sheep Canyon
Spring
Lawhon Ranch
Emigrant Hills
Shafer Ranch
Goodwin
Apache Pass
Old Fort Bowie (Ruins)
Bear Spring
Helens Dome
Bowie Mtn
Bowie Spring
Pass
Anderson
Red Mtn
Prospect
Big Sand Wash
FORT BOWIE MILITARY RESERVATION BDY (ABAN'D)
FORT BOWIE MILITARY RESERVATION
Qal
Kb
Ph
Dp
Me
Cb
pCa
pCp
pCr
pCs
Tf
Tim
Tank
Canyon
Spring
Mine
Cem
Siphon
Cutoff
Wash
Windmill
BM 4178
BM 4315
BM 4465
BM 4956
BM 4908
VABM 4235
VABM 5970


29 E
20'
R 30 E
780 000 FEET
109°15'
R 30 E
Drew Tank
Government Tank
East Windmill
Tank
Water Tank
Roosevelt Tank
Rattlesnake Point
Muleshoe Ranch
NATIONAL FOREST BOUNDARY
Wood Mtn
Rough Mtn
Dug Road Mtn
Emigrant Pass
Sunn Springs Mtn
Outlaw Springs
Triangle
San Simon Head
Cochise Head
Lumber Mtn
Brushy Canyon
Wood Canyon
Cottonwood Creek
Brad Creek
Wood Canyon South Fork
Pipe Line
CORONADO
SANTA CRUZ
SONOITA VALLEY

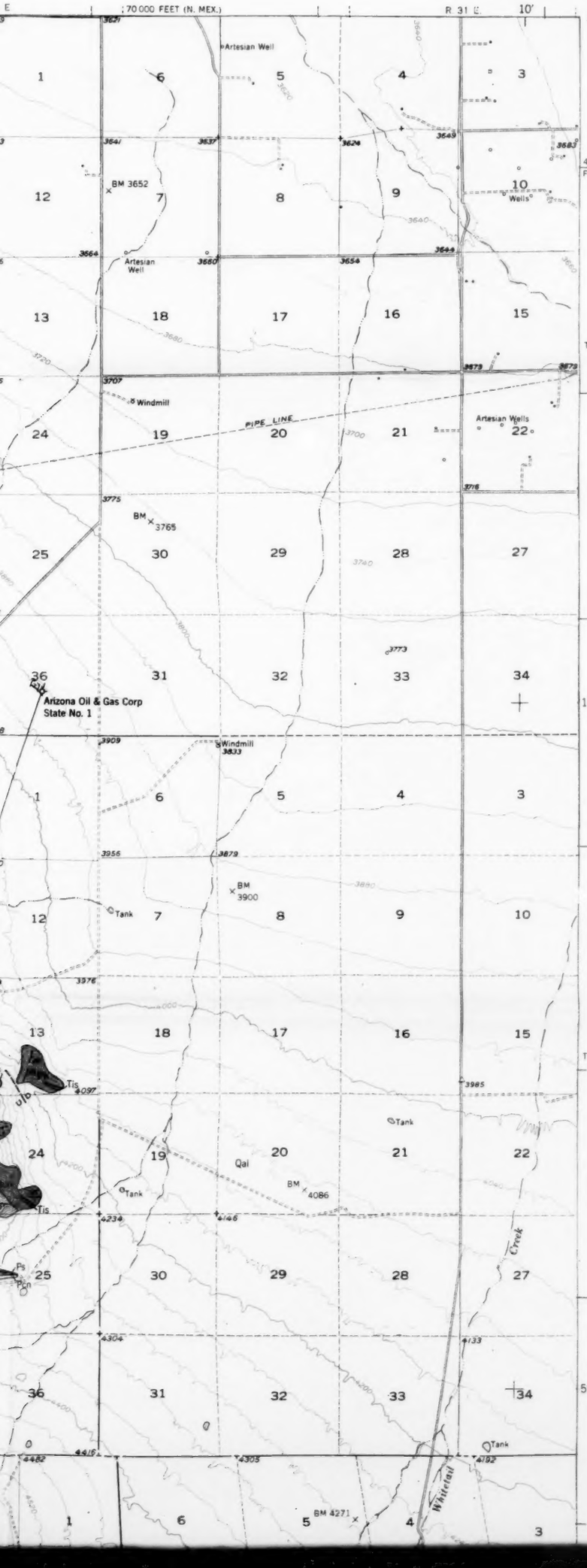

R. 30 E.
780,000 FEET
109°15'
Drew Tank
Government Tank
East Windmill
Tank
Water Tank
Roosevelt Tank 6
Rattlesnake Point
Canyon
Mullkins Ranch
NATIONAL FOREST BOUNDARY
Wood Mtn
VABM 7323
Rough Mtn
7282
Dun Springs Mtn
Duck Road Mtn
Hells Half Acre
Emigrant Pass
Wood Canyon
South Fork
Cottonwood Creek
Outlaw Springs
Triangle
Brushy Canyon
San Simon Head
5717
C O R O N A D O
SANTA CRUZ
SONOITA VALLEY
PIPE LINE

Sabins, Pl. 1


70 000 FEET (N. MEX.)
R. 31 E.
10'
32° 15'
Artesian Well
Windmill
PIPE LINE
Artesian Wells
BM 3652
BM 3765
BM 3900
BM 4088
BM 4271
Arizona Oil & Gas Corp
State No. 1
Tank
Wells
Creek
Whitetail
T. 24 S.
T. 25 S.
450 000 FEET (ARIZ.)
EXPLANATION
Qal
Alluvium
UNCONFORMITY
Tis
Silicic intrusives
Tim
Mafic intrusives
Intrusive rocks
Tr
Rhyolite Canyon Formation
Tf
Faraway Ranch Formation
TERTIARY
QUATERNARY
UNCONFORMITY
TKn
Nipper Formation
UNCONFORMITY
Kb
Middle and upper Bisbee Group
Kg
Glance Conglomerate
Comanche Series
Bisbee Group
CRETACEOUS
UNCONFORMITY
Pcn
Concha Limestone
Ps
Scherrer Formation
Pcl
Colina Limestone
PPe
Earp Formation
Ph
Horquilla Limestone
Naco Group
PERMIAN
PENNSYLVANIAN
DISCONFORMITY
Mp
Paradise Formation
Me
Escabrosa Limestone
Upper Mississippian
Lower Mississippian
MISSISSIPPIAN
DISCONFORMITY
Dp
Portal Formation
Upper Devonian
DEVONIAN
DISCONFORMITY
OCe
El Paso Formation
Cb
Bolsa Quartzite
Middle (?) Upper Cambrian and Upper Cambrian
Lower Ordovician
CAMBRIAN
ORDOVICIAN
UNCONFORMITY
pCa
Aplite dikes
pCr
Rattlesnake Point Granite
pCs
Sheep Canyon Granite
Intrusive rocks
PRECAMBRIAN

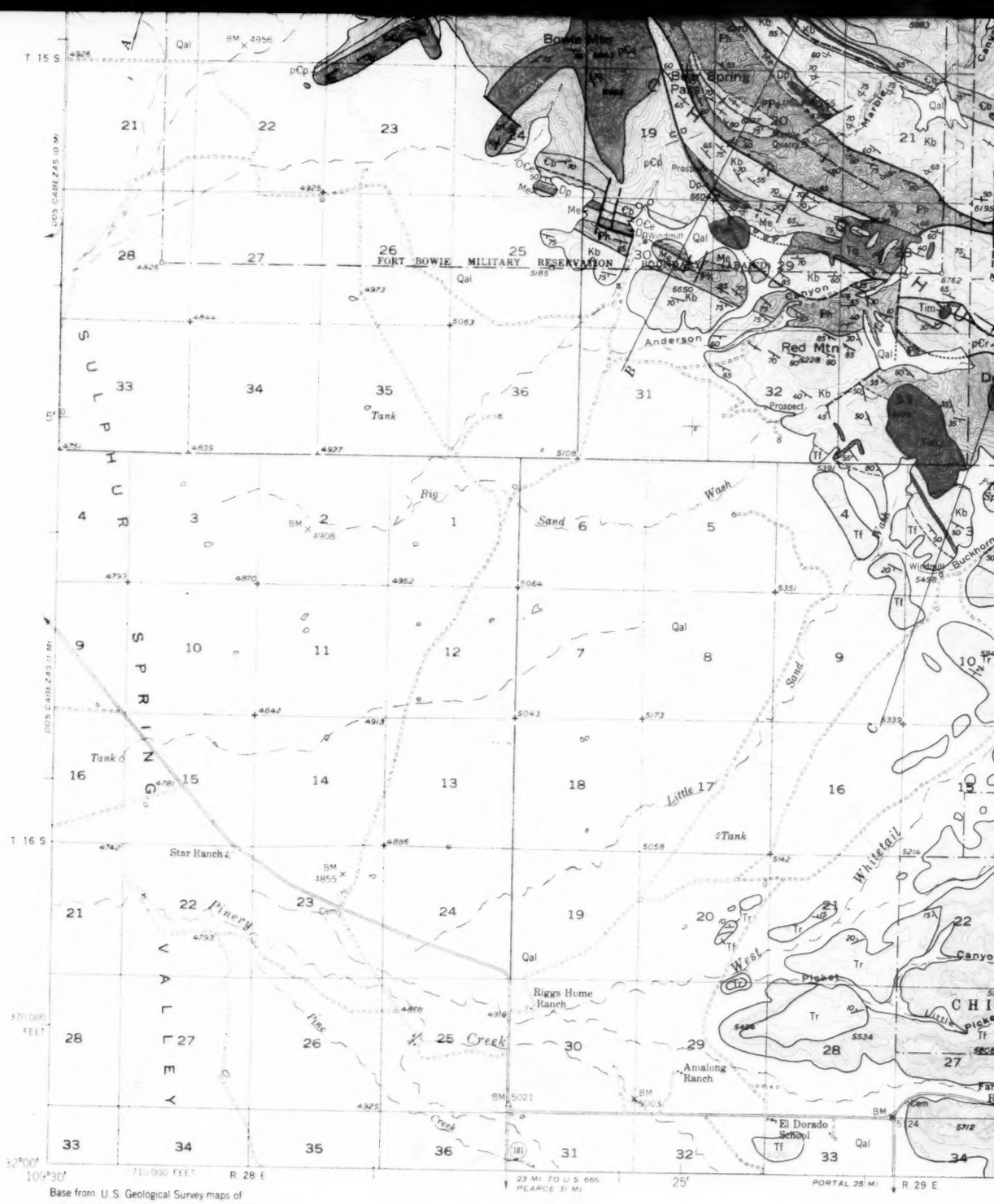

R. 30 E.
780 000 FEET
109°15'
R. 30 E.
Drew Tank
Government Tank
East Windmill
Windmill
BM 3676
BM 3822
BM 4039
Tank
Water Tank
Roosevelt Tank 6
Rattlesnake Point
Canyon
Wood
Creek
Rough Mtn
Emigrant Pass
Halls Mill Area
Mustang Ranch
BOUNDARY
Cross Windmill
Outlaw Springs
Whitehouse Mine
San Simon
Head
Canyon
Qal
pCr
Kb
Tis
Tf
Ps
Pcl
Pcn
PPe
Me
Dp
Tim
Kg
C O R O N A D O

Sabins, Pl. 1

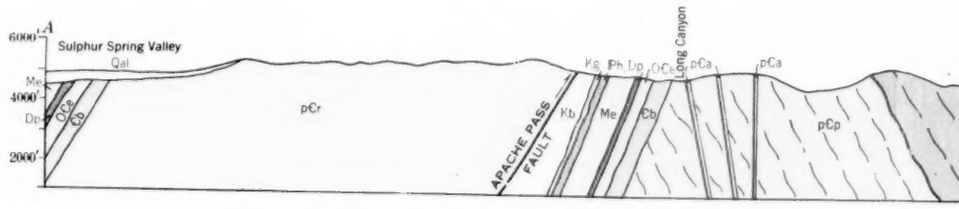


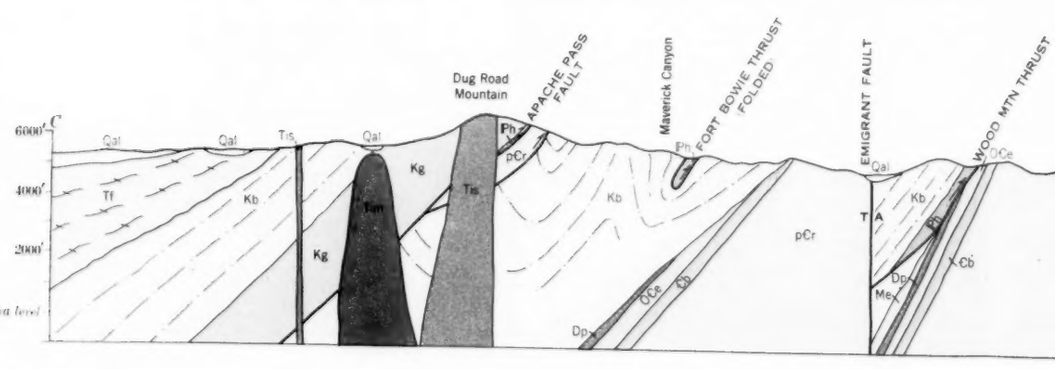
EXPLANATION

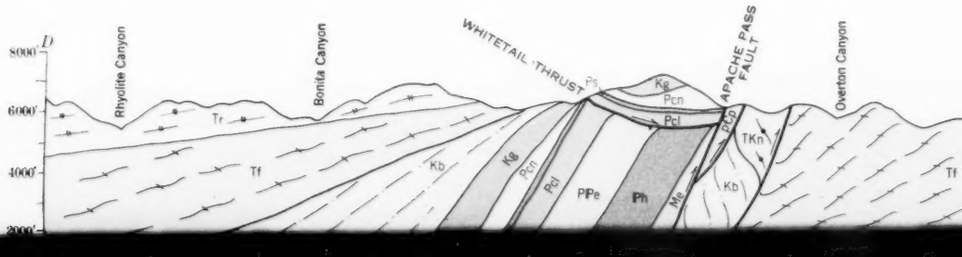
	Qal	Alluvium	QUATERNARY
	UNCONFORMITY		
Intrusive rocks	Tis	Silicic intrusives	TERTIARY
Intrusive rocks	Tmi	Mafic intrusives	TERTIARY
	Tr	Rhyolite Canyon Formation	TERTIARY
	Tf	Faraway Ranch Formation	TERTIARY
	UNCONFORMITY		
	TKn	Nipper Formation	CRETACEOUS
	UNCONFORMITY		
Comanche Series, Bisbee Group	Kb	Middle and upper Bisbee Group	CRETACEOUS
Comanche Series, Bisbee Group	Kg	Glance Conglomerate	CRETACEOUS
	UNCONFORMITY		
Naco Group	Pcn	Concha Limestone	PERMIAN
Naco Group	Ps	Scherrer Formation	PERMIAN
Naco Group	Pcl	Colina Limestone	PERMIAN
Naco Group	PPe	Earp Formation	PENNSYLVANIAN
Naco Group	Ph	Horquilla Limestone	PENNSYLVANIAN
	DISCONFORMITY		
Upper Mississippian	Mp	Paradise Formation	MISSISSIPPIAN
Lower Mississippian	Me	Escabrosa Limestone	MISSISSIPPIAN
	DISCONFORMITY		
Upper Devonian	Dp	Portal Formation	DEVONIAN
	DISCONFORMITY		
Middle (?) and Upper Cambrian, Upper Cambrian and Lower Ordovician	OCe	El Paso Formation	CAMBRIAN ORDOVICIAN
Middle (?) and Upper Cambrian, Upper Cambrian and Lower Ordovician	Cb	Bolsa Quartzite	CAMBRIAN ORDOVICIAN
	UNCONFORMITY		
Intrusive rocks	pCa	Aplite dikes	PRECAMBRIAN
Intrusive rocks	pCr	Rattlesnake Point Granite	PRECAMBRIAN
Intrusive rocks	pCs	Sheep Canyon Granite	PRECAMBRIAN

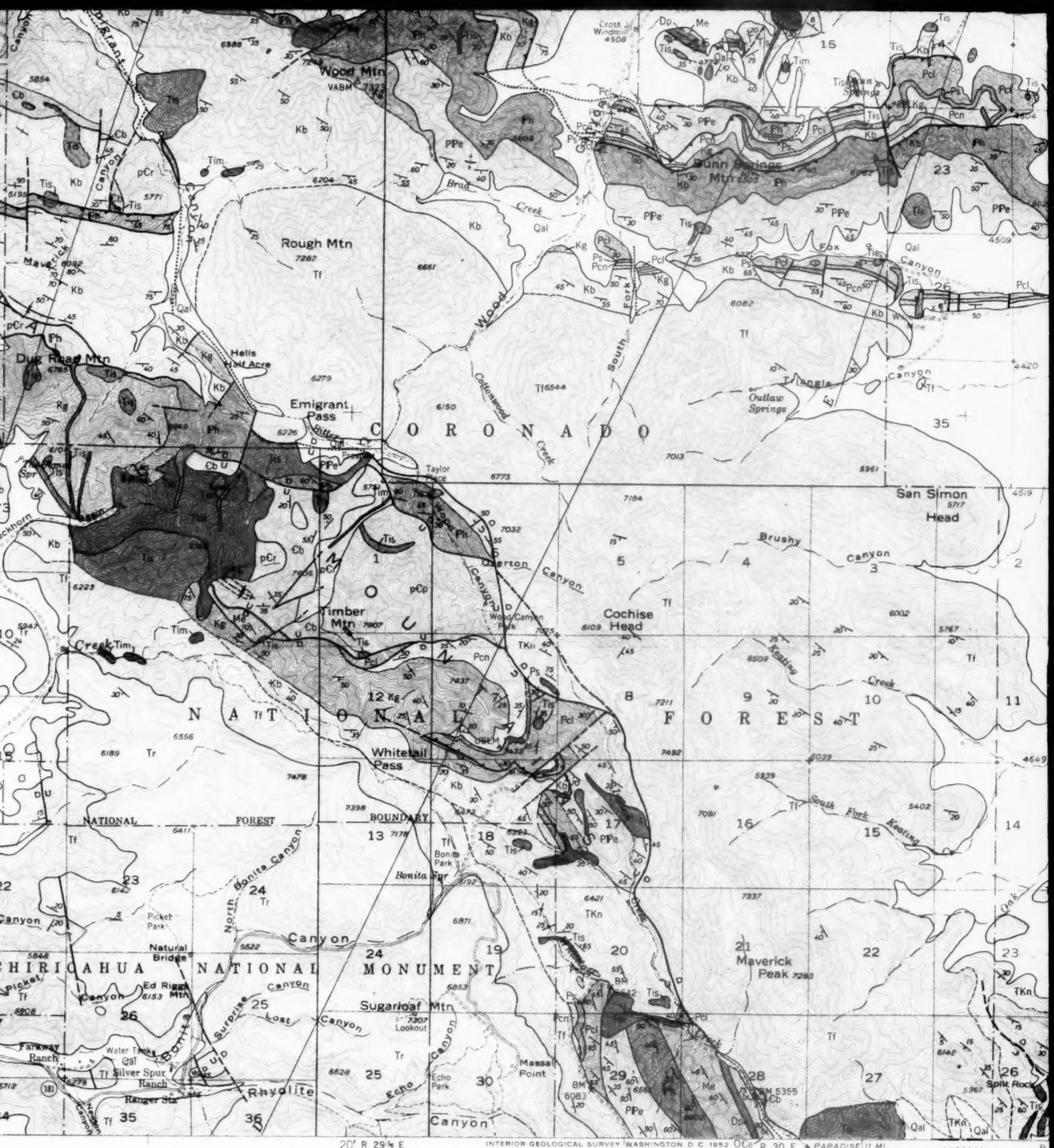


Base from U.S. Geological Survey maps of Cochise Head and Vanar quadrangles, 1950

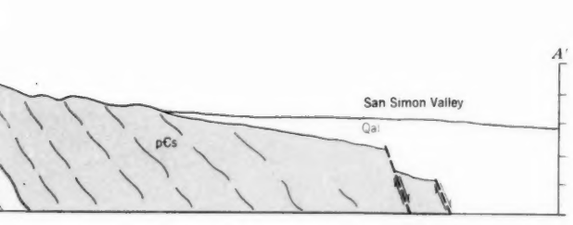


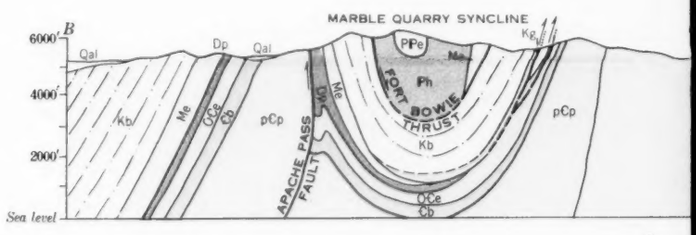


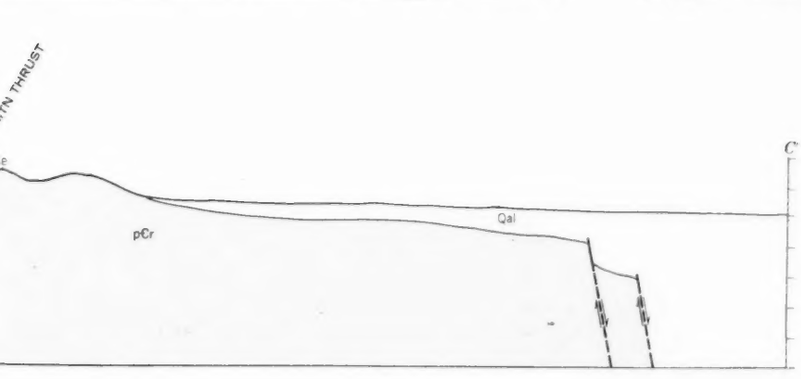




Cochise Head Quadrangle Ŵanar Quadrangle







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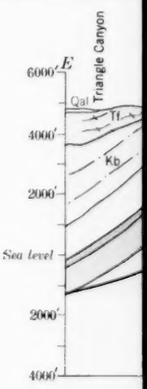
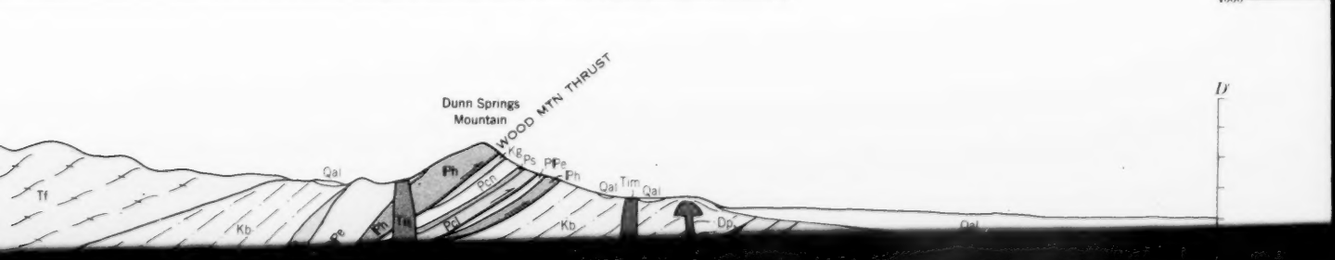
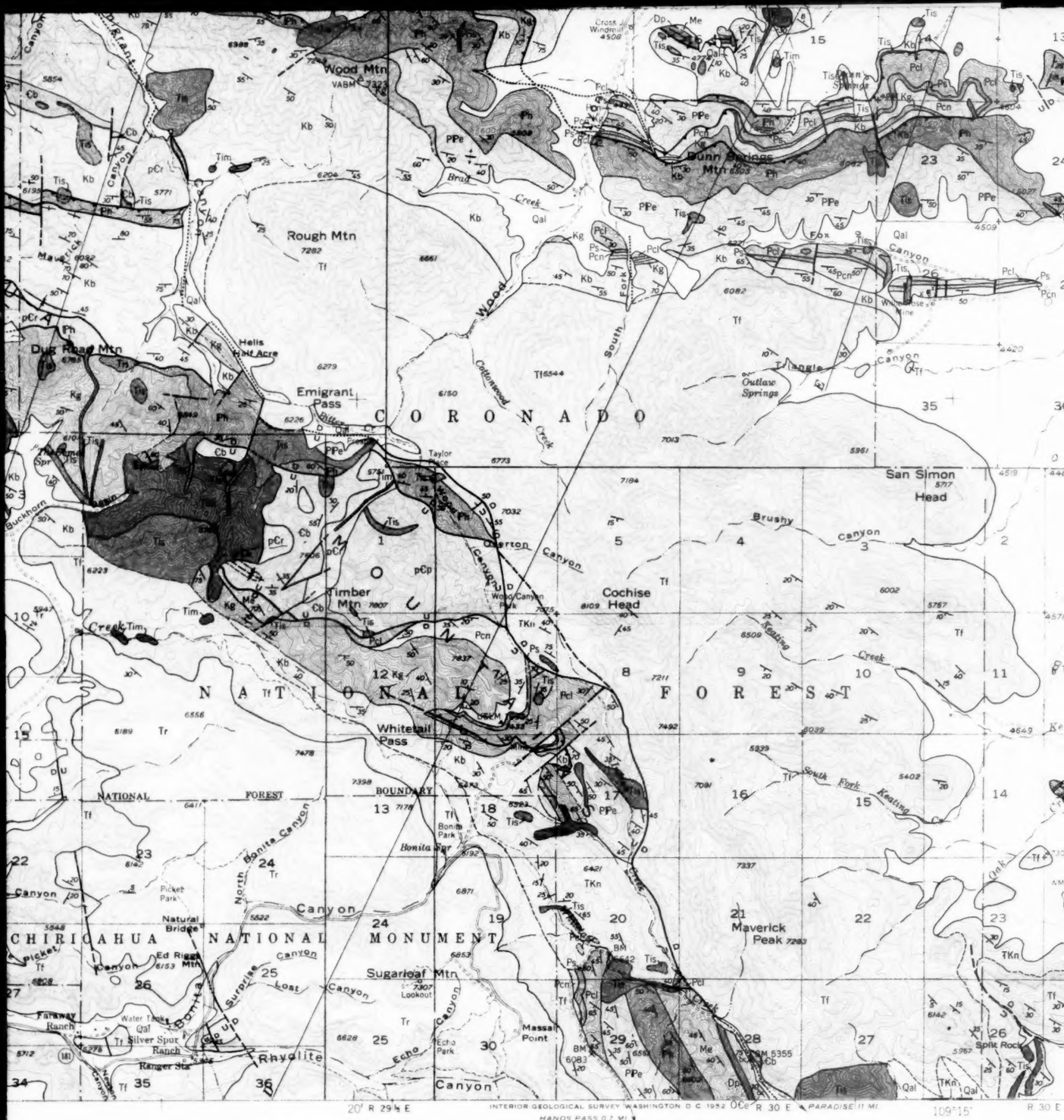
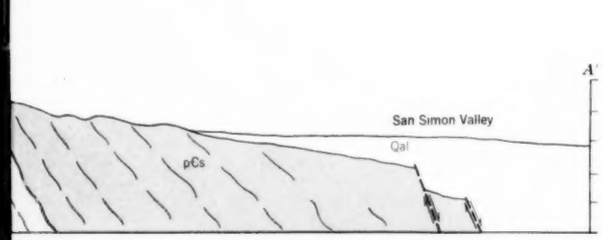
T, toward reader

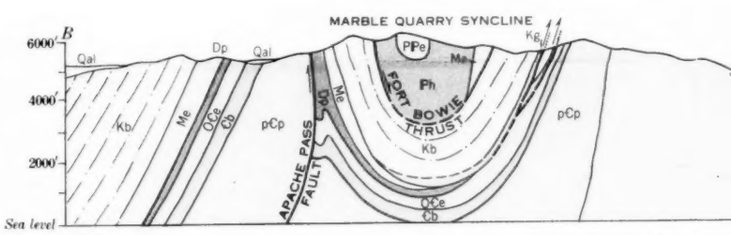


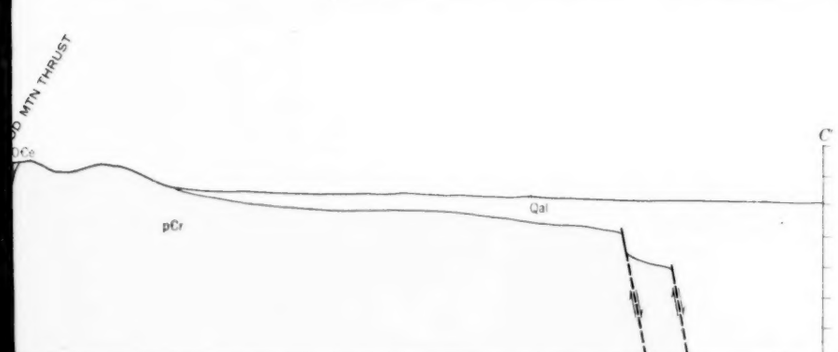




Cochise Head Quadrangle Vanar Quadrangle







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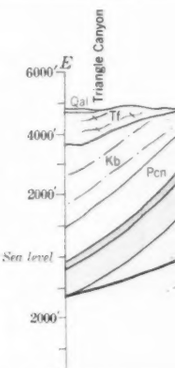
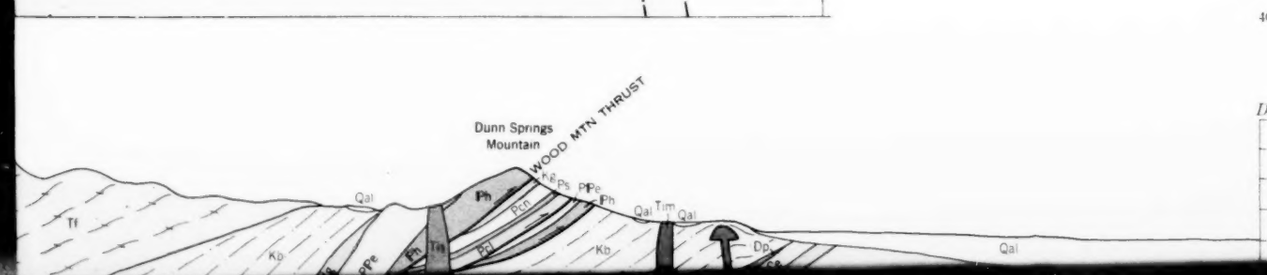
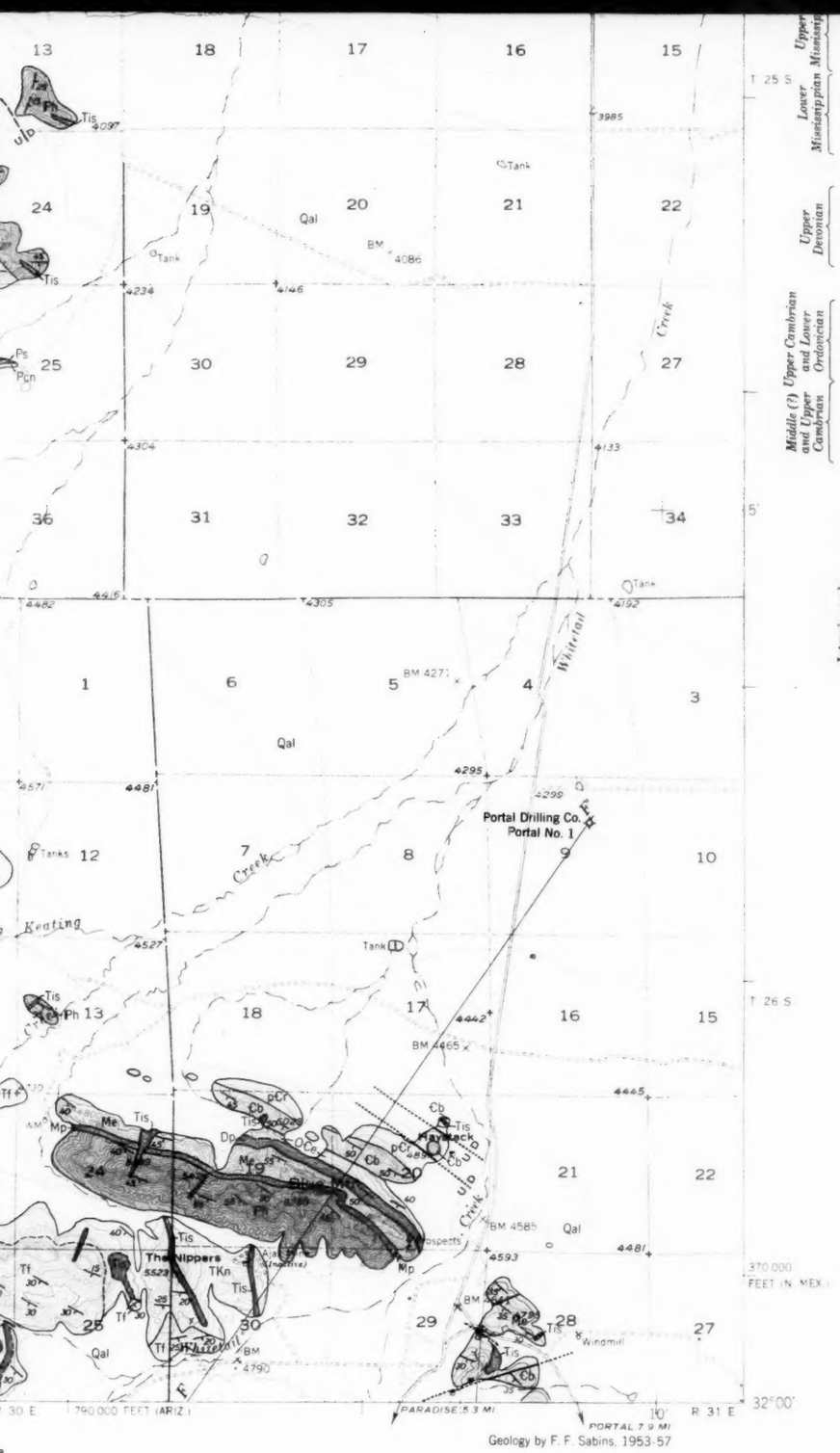
T, toward reader







Geology by F. F. Sabins, 1953-57

Contact, dashed where approximately located

High angle dip slip fault
Dashed where approximately located.
U, *upthrown side*; D, *downthrown side*

Thrust fault
Points of triangles are toward thrust plate

Strike slip fault

Concealed fault

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

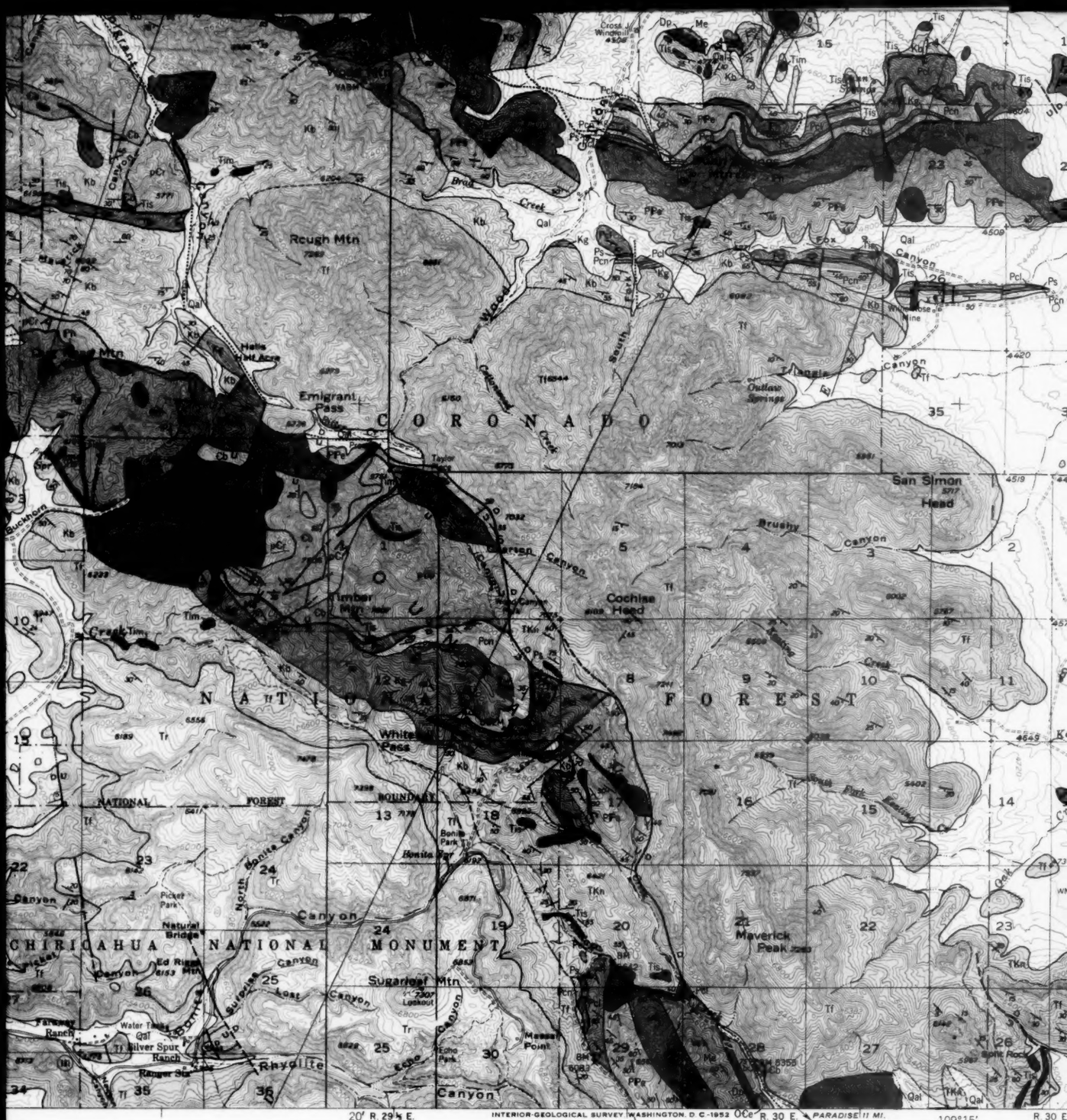
Strike and dip of foliation

Strike of vertical foliation

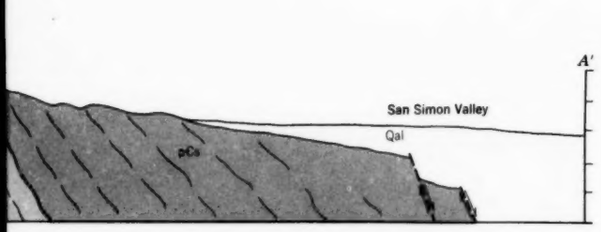
Axis of anticline

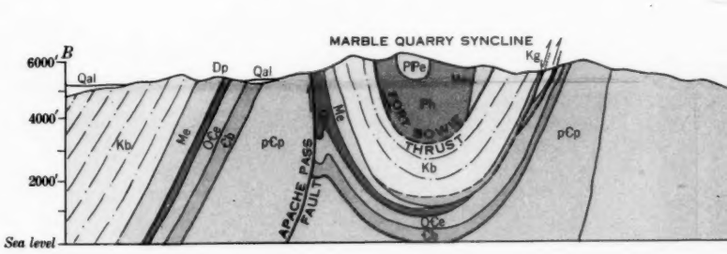
Axis of syncline

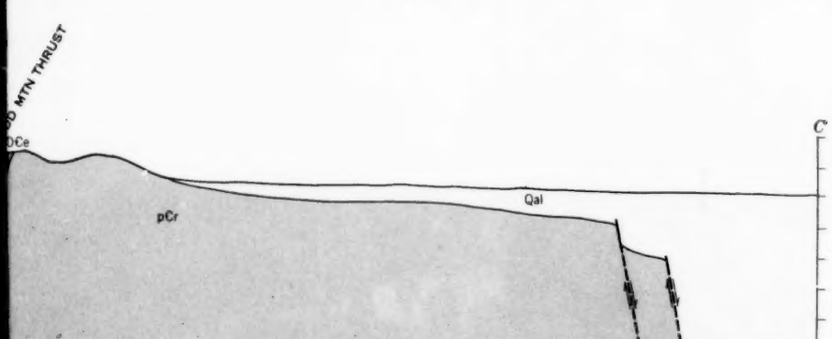
Dry hole (oil)



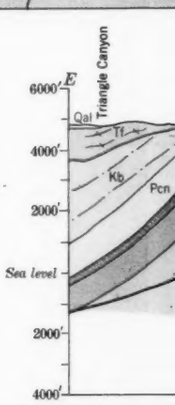
Cochise Head Quadrangle Vanar Quadrangle

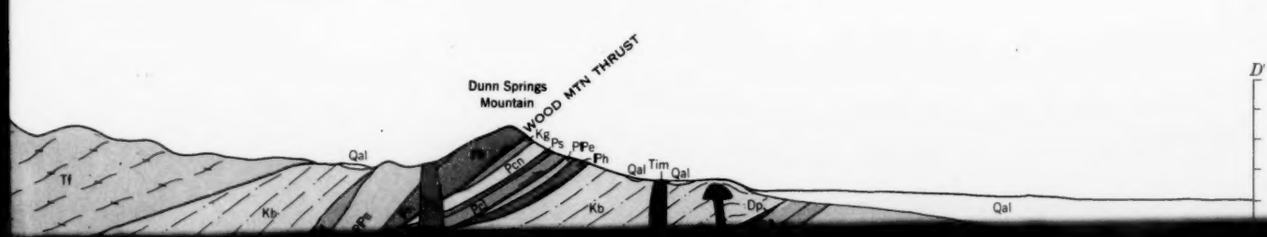


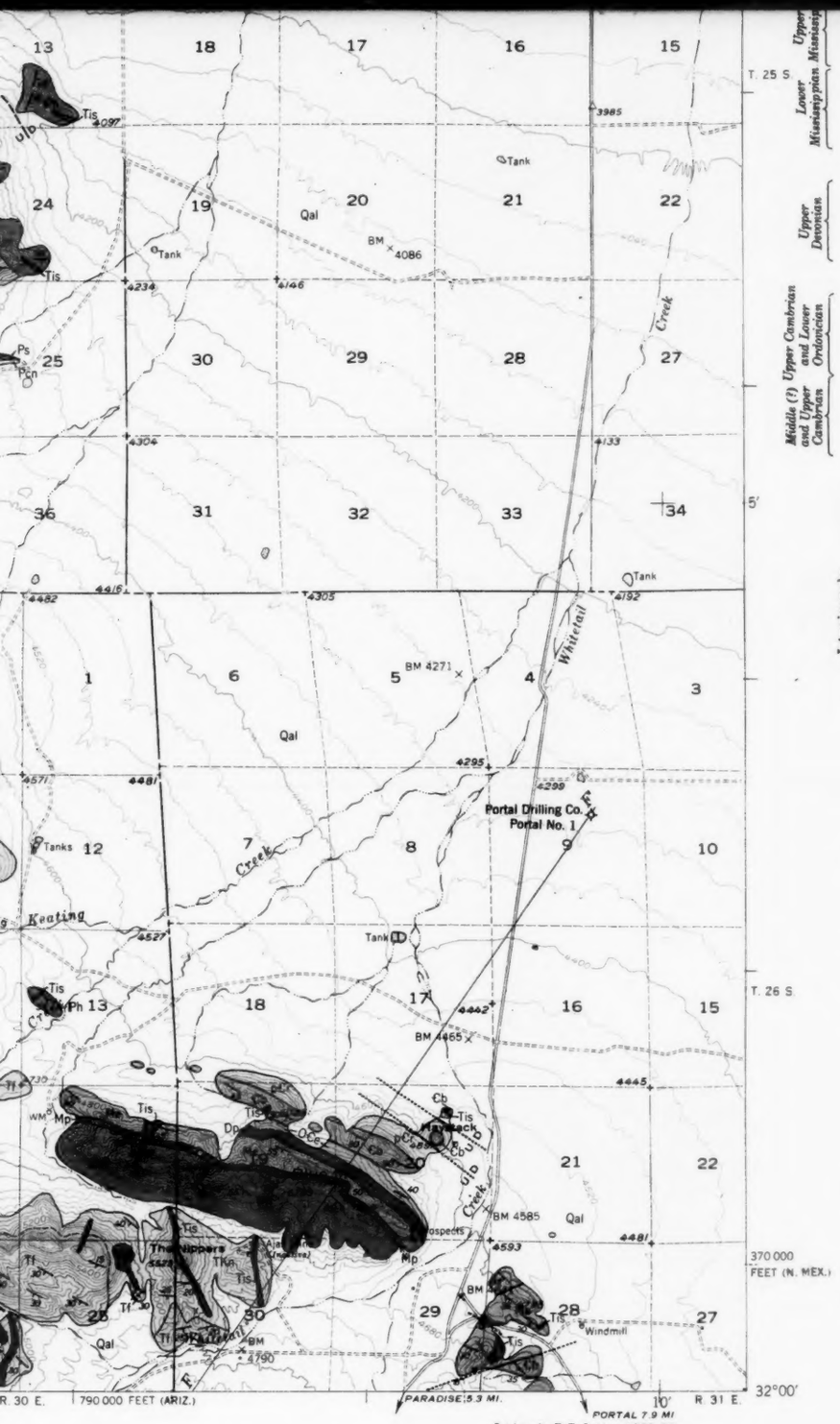




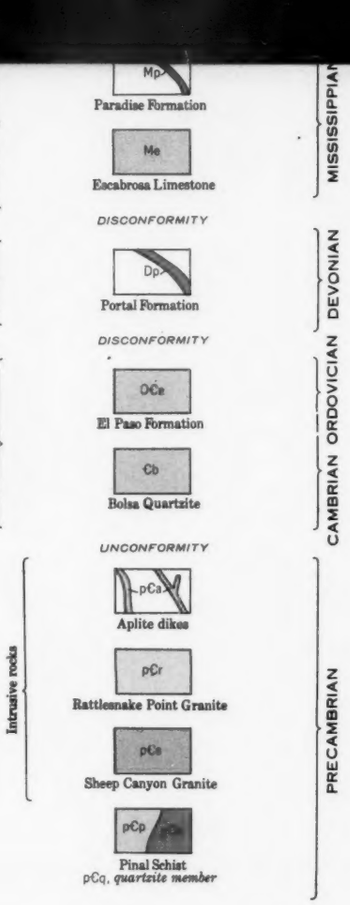
A, away from reader
T, toward reader







Geology by F. F. Sabins, 1953-57



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Strike and dip of overturned beds

Strike of vertical beds

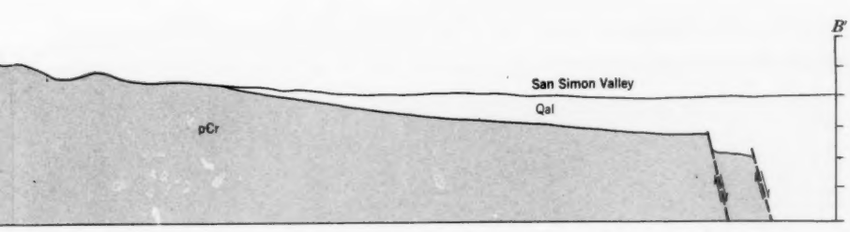
Strike and dip of foliation

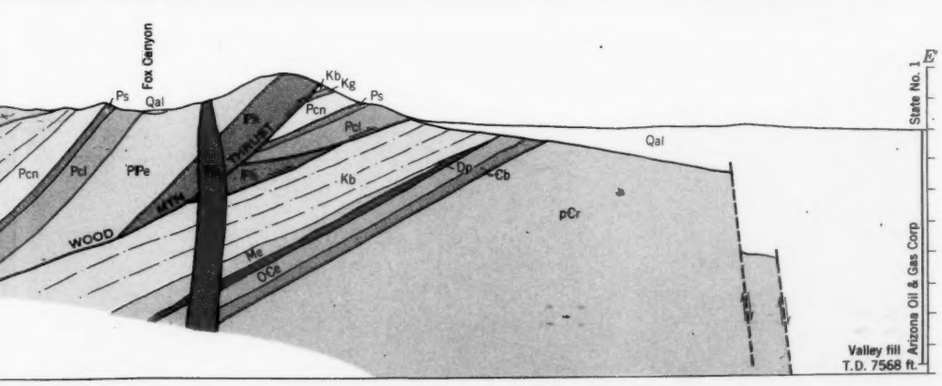
Strike of vertical foliation

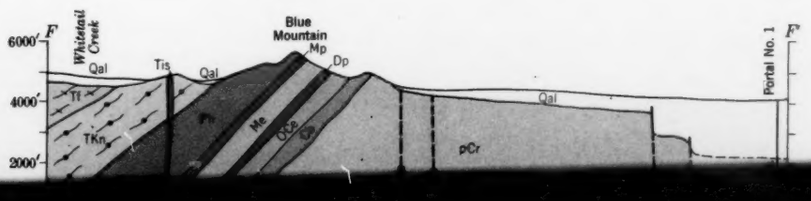
Axis of anticline

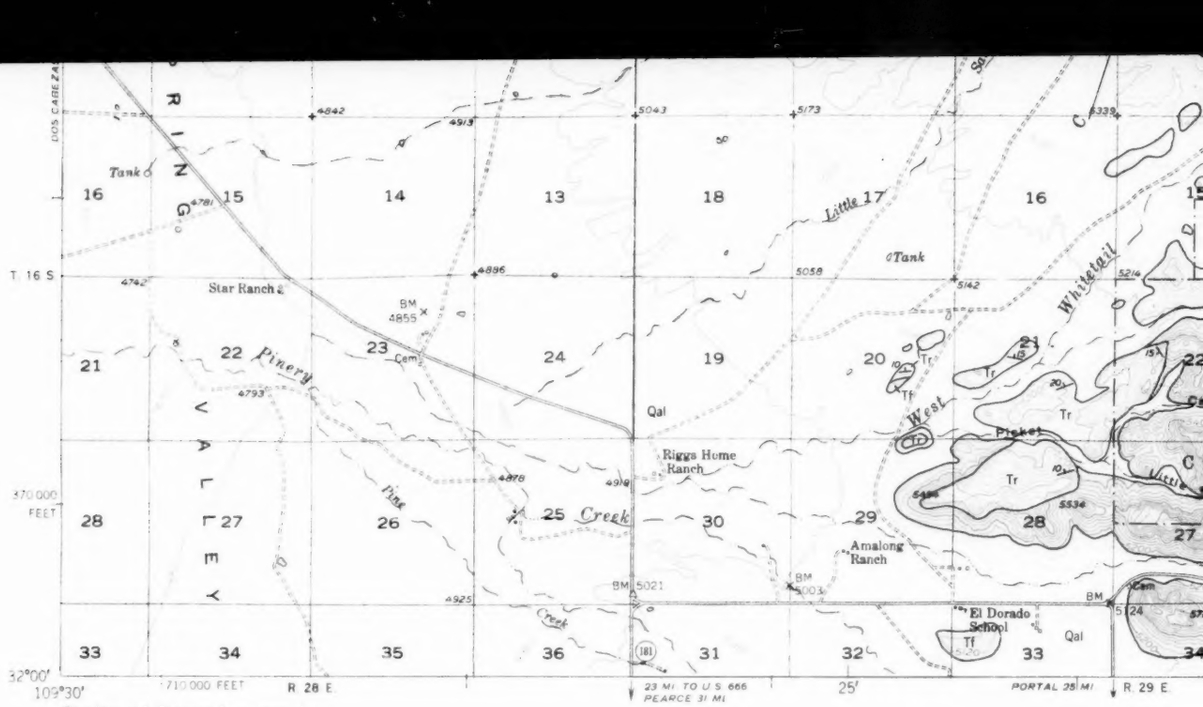
Axis of syncline

Dry hole (oil)

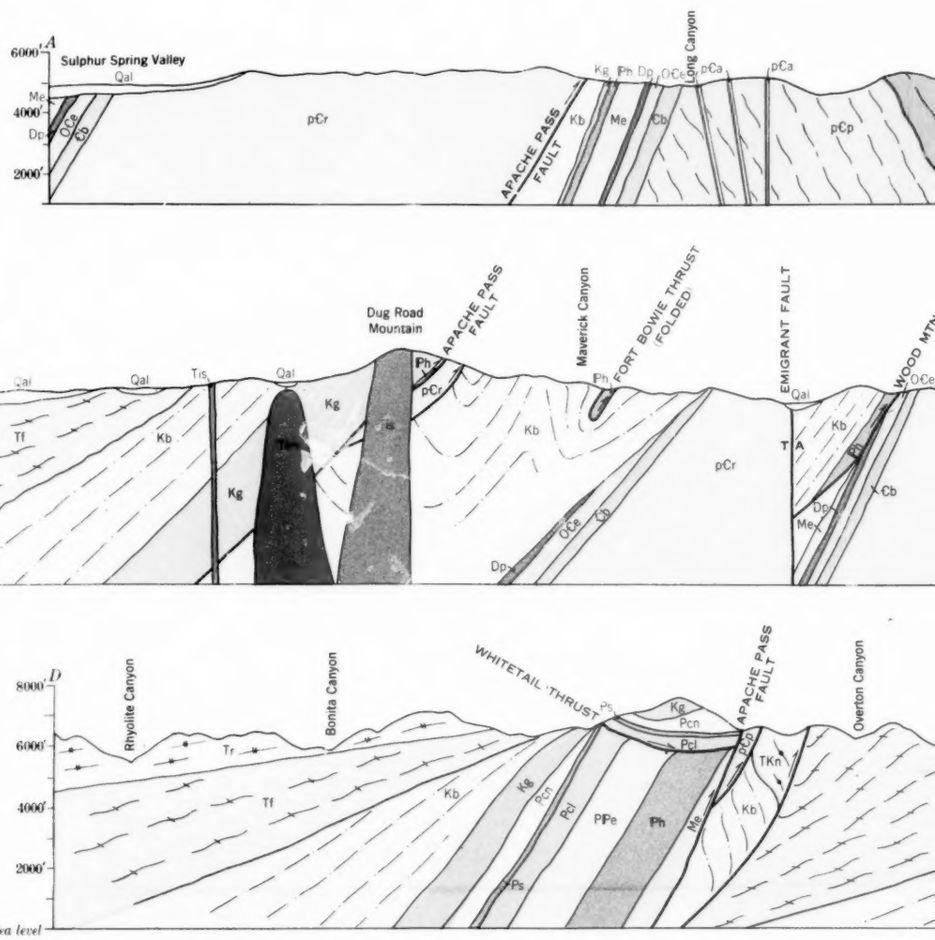






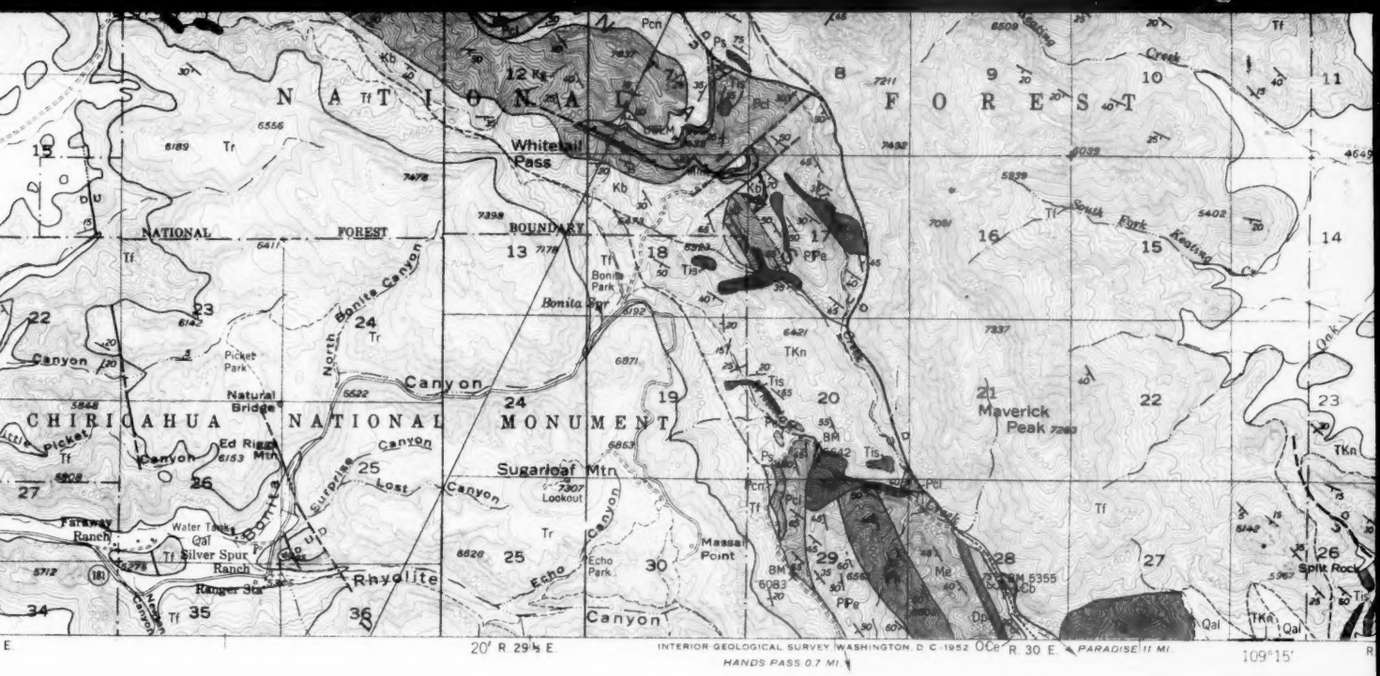


Base from U. S. Geological Survey maps of Cochise Head and Vanar quadrangles, 1950

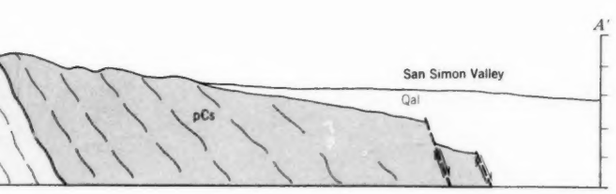


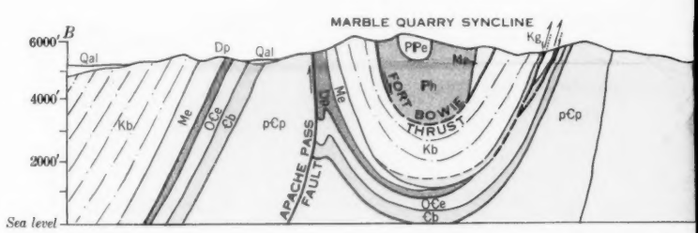
GEOLOGIC MAP AND SECTIO

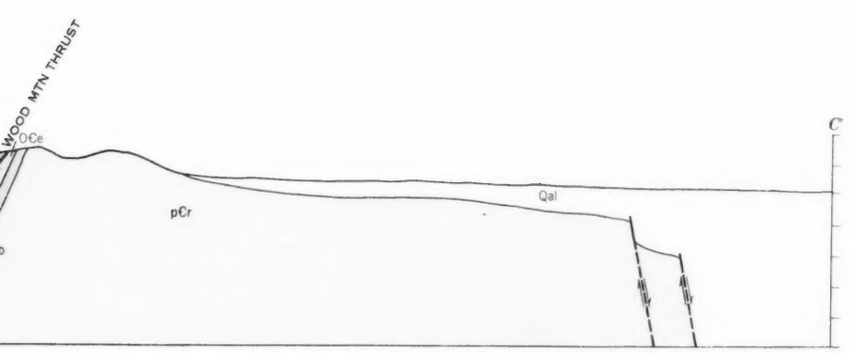
APPROXIMATE MEAN DECLINATION, 1950



Cochise Head Quadrangle Vanar Quadrangle







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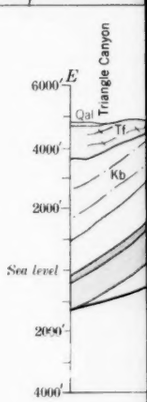
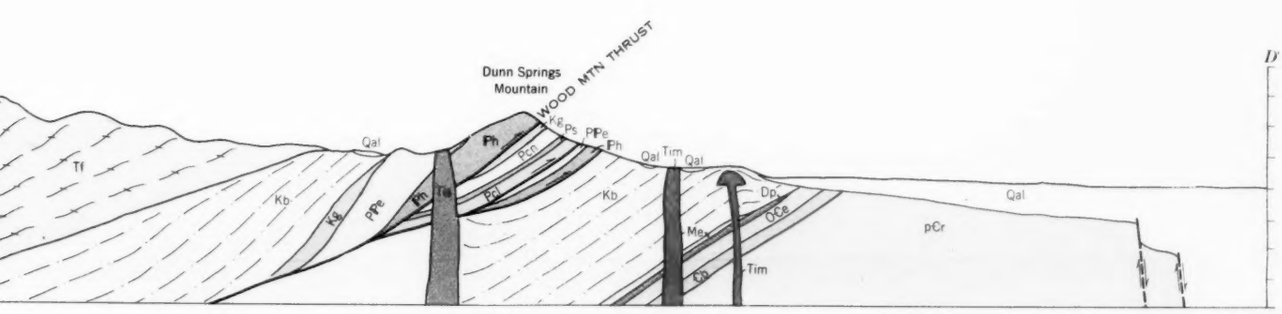
T, toward reader





TIONS OF THE COCHISE HEAD AND WESTERN PART OF VANAR QU

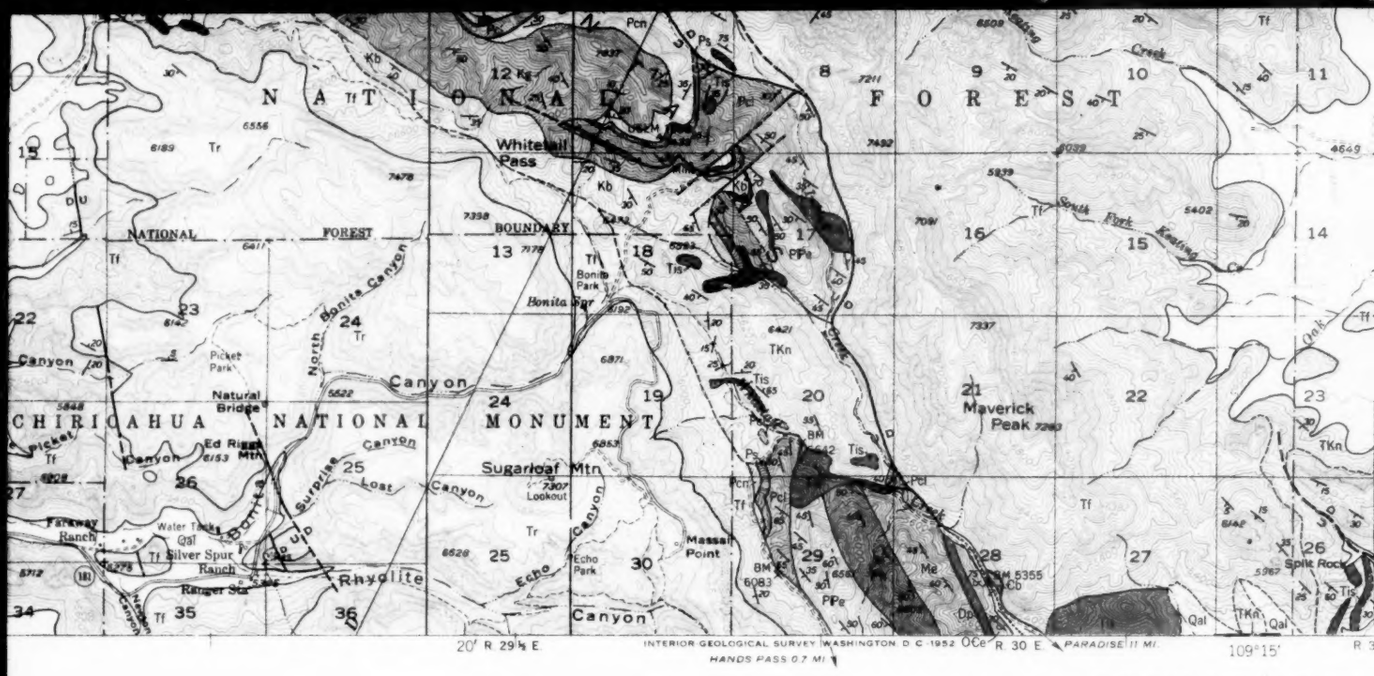
SCALE 1:62500

1 0 1 2 3 4 MILES

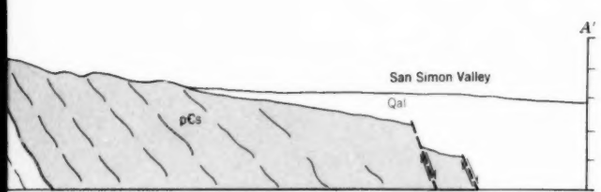
3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

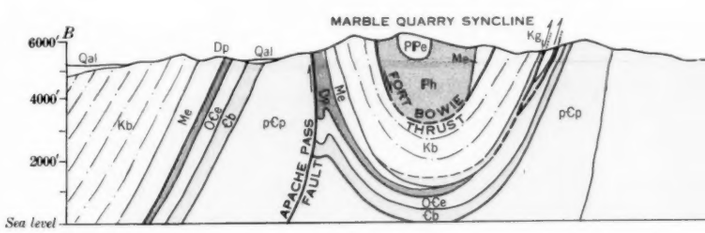
1 5 0 1 2 3 4 5 KILOMETERS

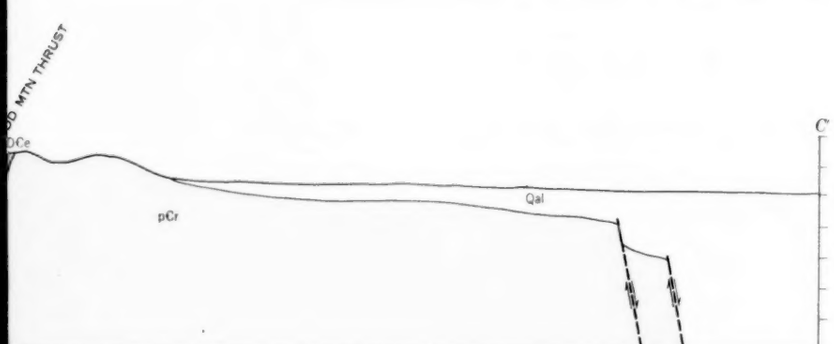
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL



Cochise Head Quadrangle Vanar Quadrangle

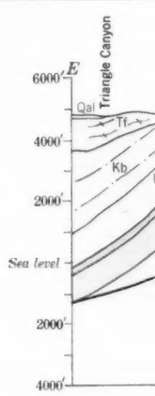


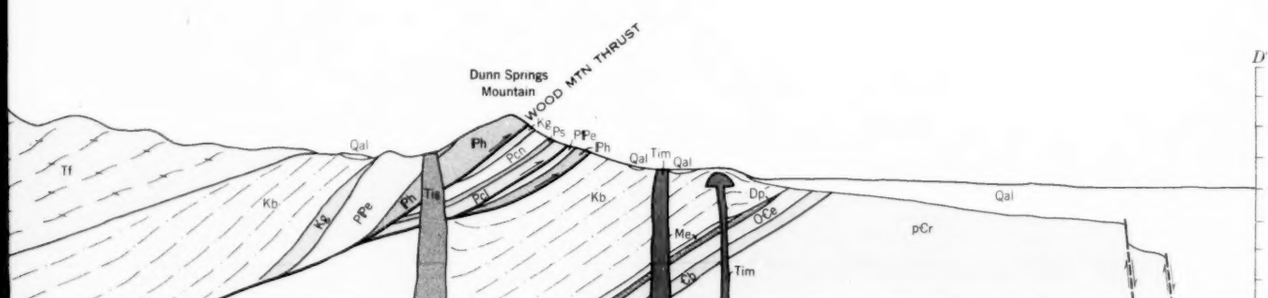




A, away from reader

T, toward reader





IONS OF THE COCHISE HEAD AND WESTERN PART OF VANAR QU

SCALE 1:62500

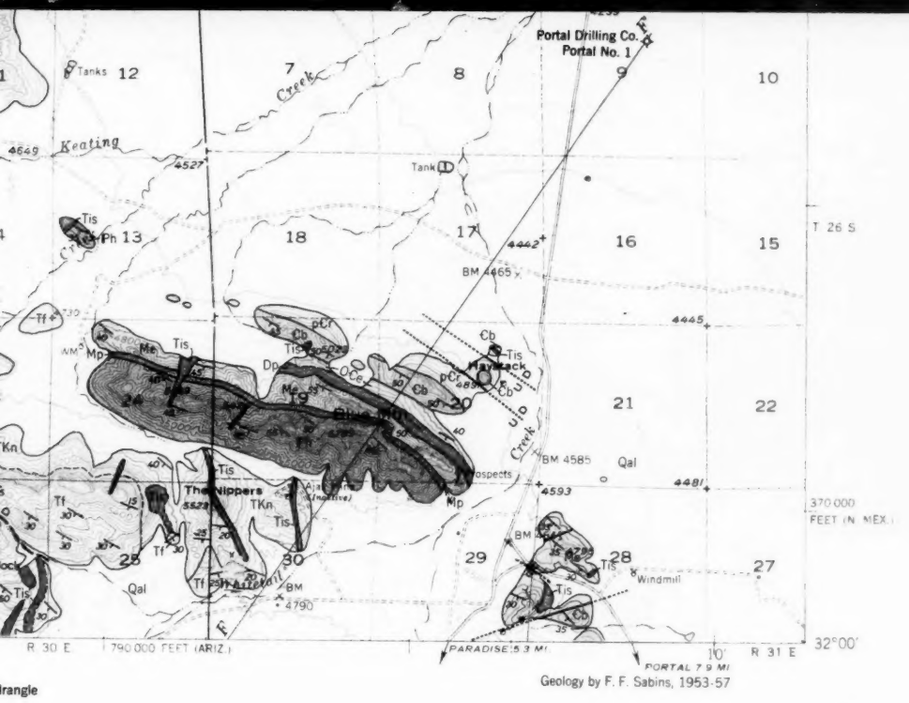
1 0 1 2 3 4 MILES

9000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 40 FEET

DATUM IS MEAN SEA LEVEL



Geology by F. F. Sabins, 1953-57

pCq, *quartzite member*

Contact, dashed where approximately located

High angle dip slip fault
Dashed where approximately located.
U, *upthrown side;* D, *downthrown side*

Thrust fault
Points of triangles are toward thrust plate

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Concealed fault

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

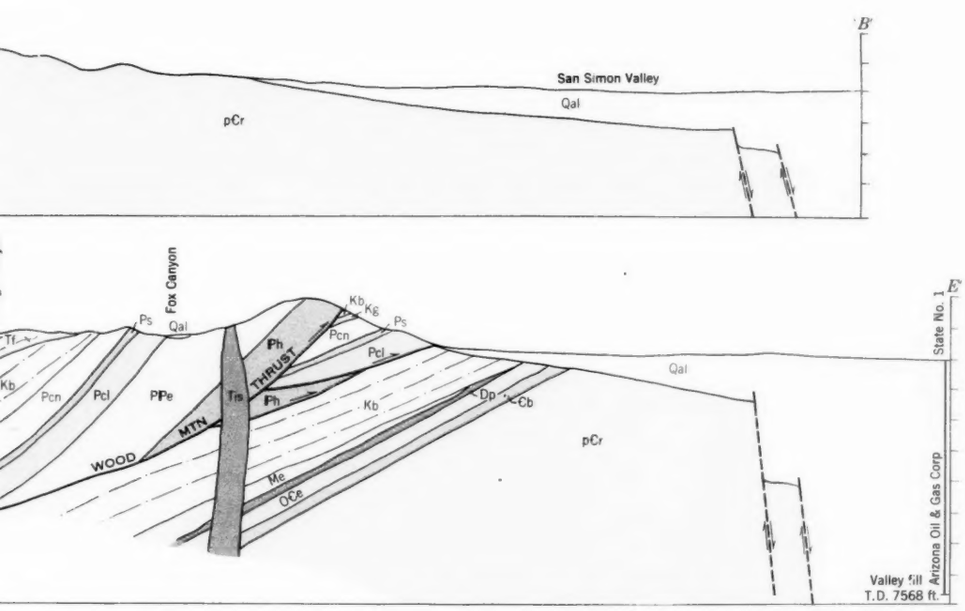
Strike and dip of foliation

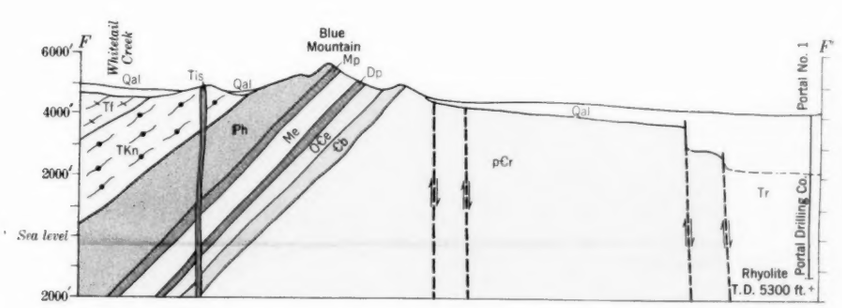
Strike of vertical foliation

Axis of anticline

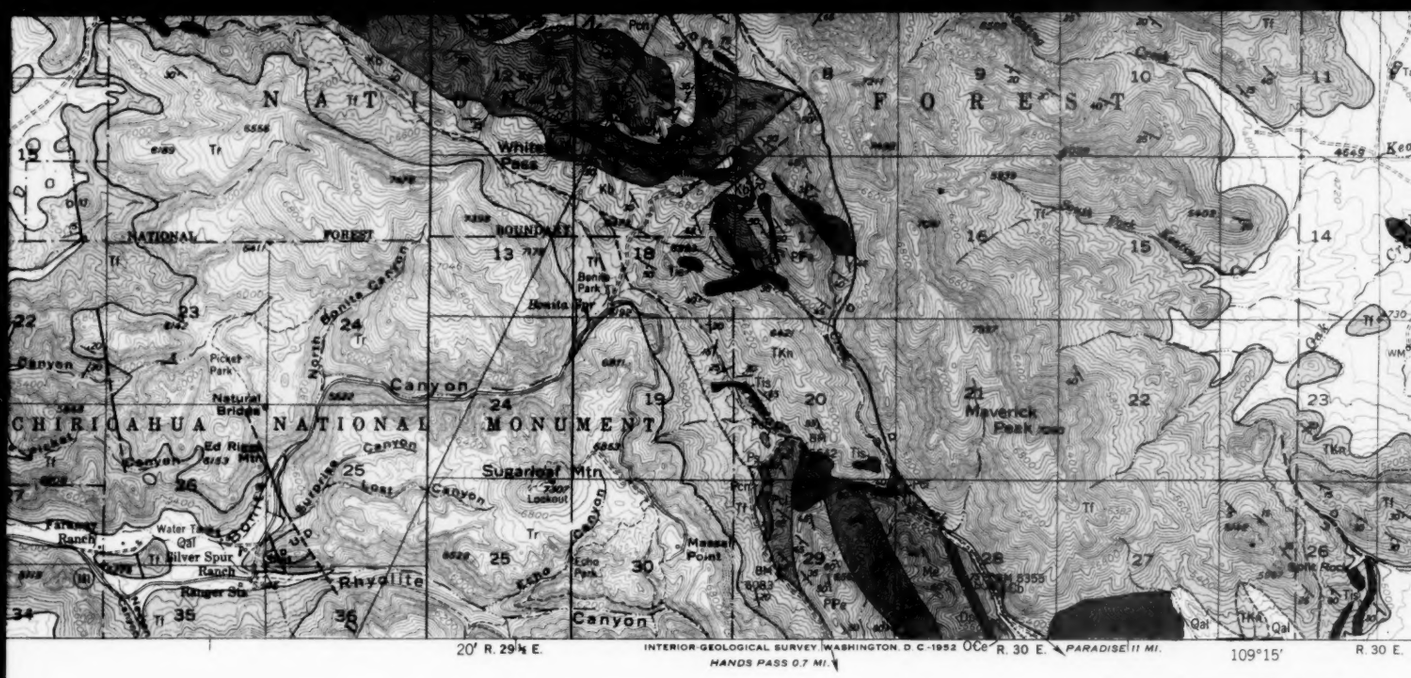
Axis of syncline

Dry hole (oil)

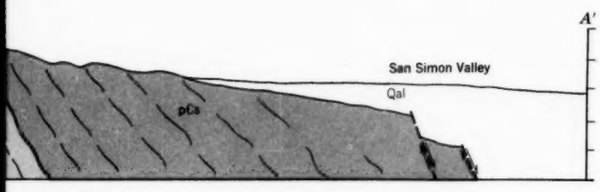


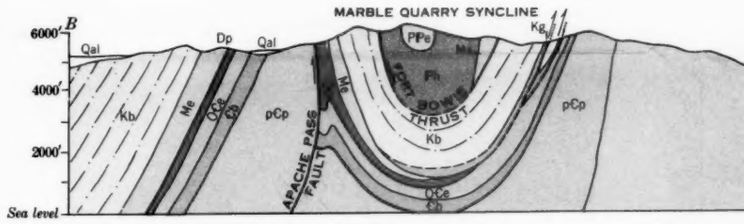


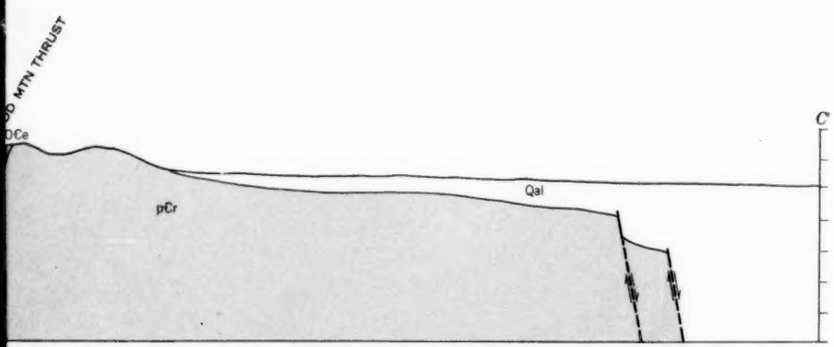
QUADRANGLES, ARIZONA



Cochise Head Quadrangle Vanar Quadrangle

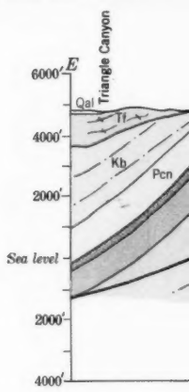


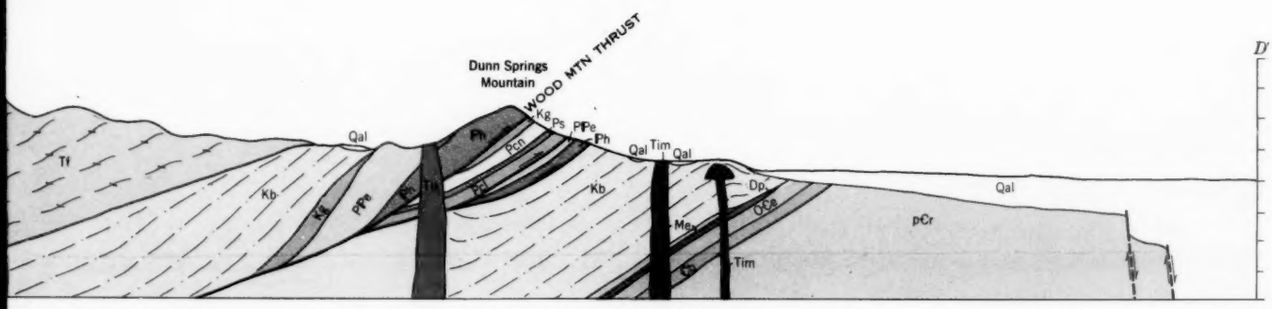




A, away from reader

T, toward reader





IONS OF THE COCHISE HEAD AND WESTERN PART OF VANAR QUA

SCALE 1:62500

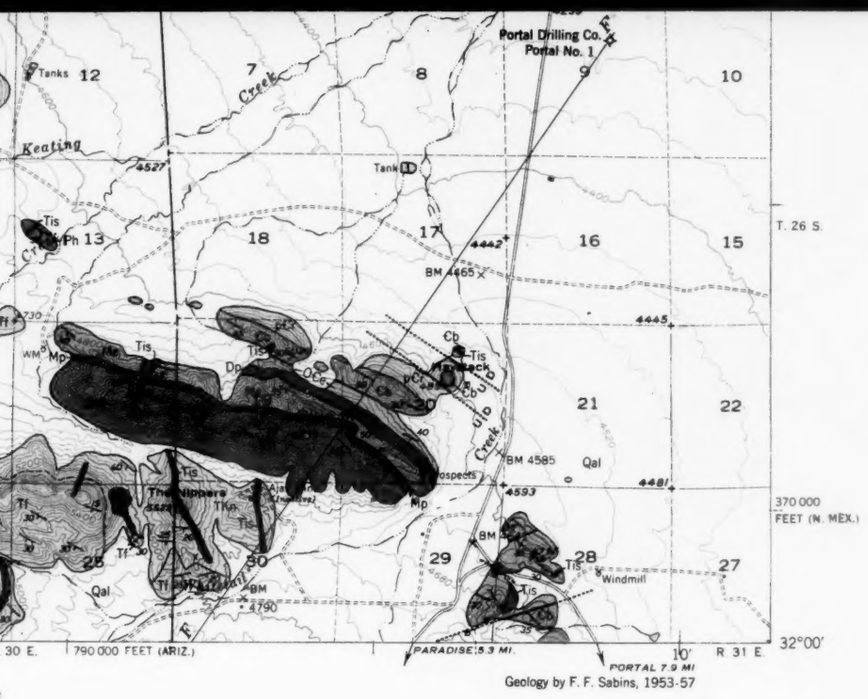
1 ½ 0 1 2 3 4 MILES

1000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 40 FEET

DATUM IS MEAN SEA LEVEL



Geology by F. F. Sabins, 1953-57

pCq, *quartzite member*

Contact, dashed where approximately located

High angle dip slip fault
Dashed where approximately located.
U, *upthrown side;* D, *downthrown side*

Thrust fault
Points of triangles are toward thrust plate

Strike slip fault

Concealed fault

Strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds

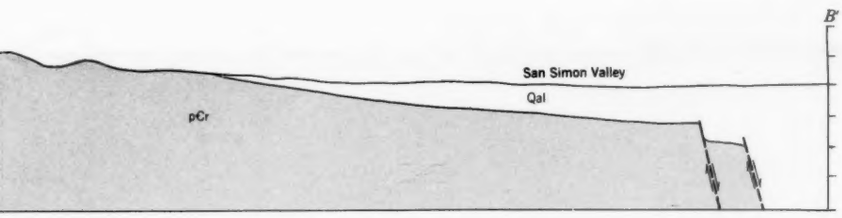
Strike and dip of foliation

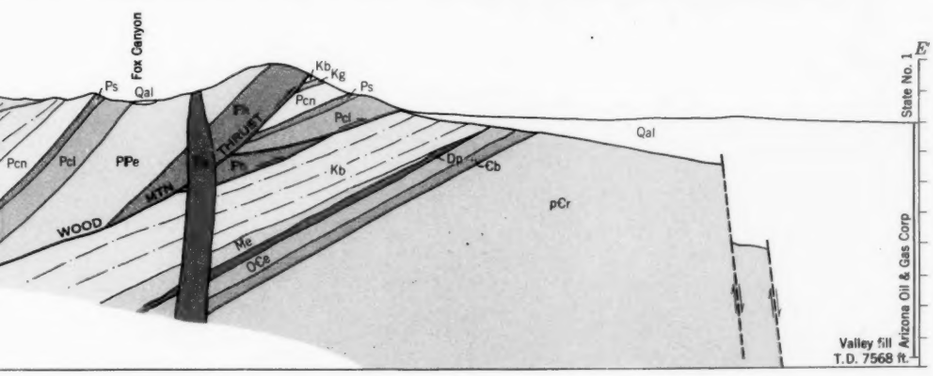
Strike of vertical foliation

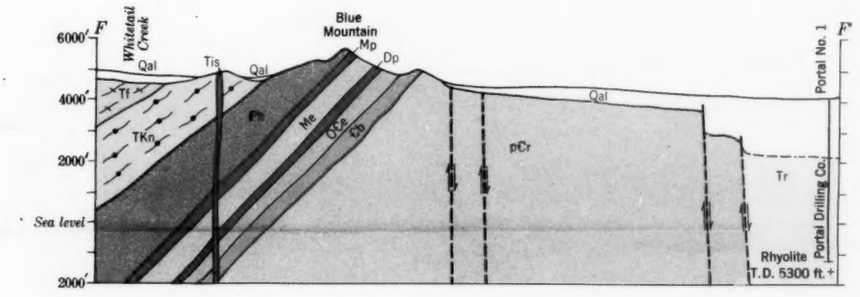
Axis of anticline

Axis of syncline

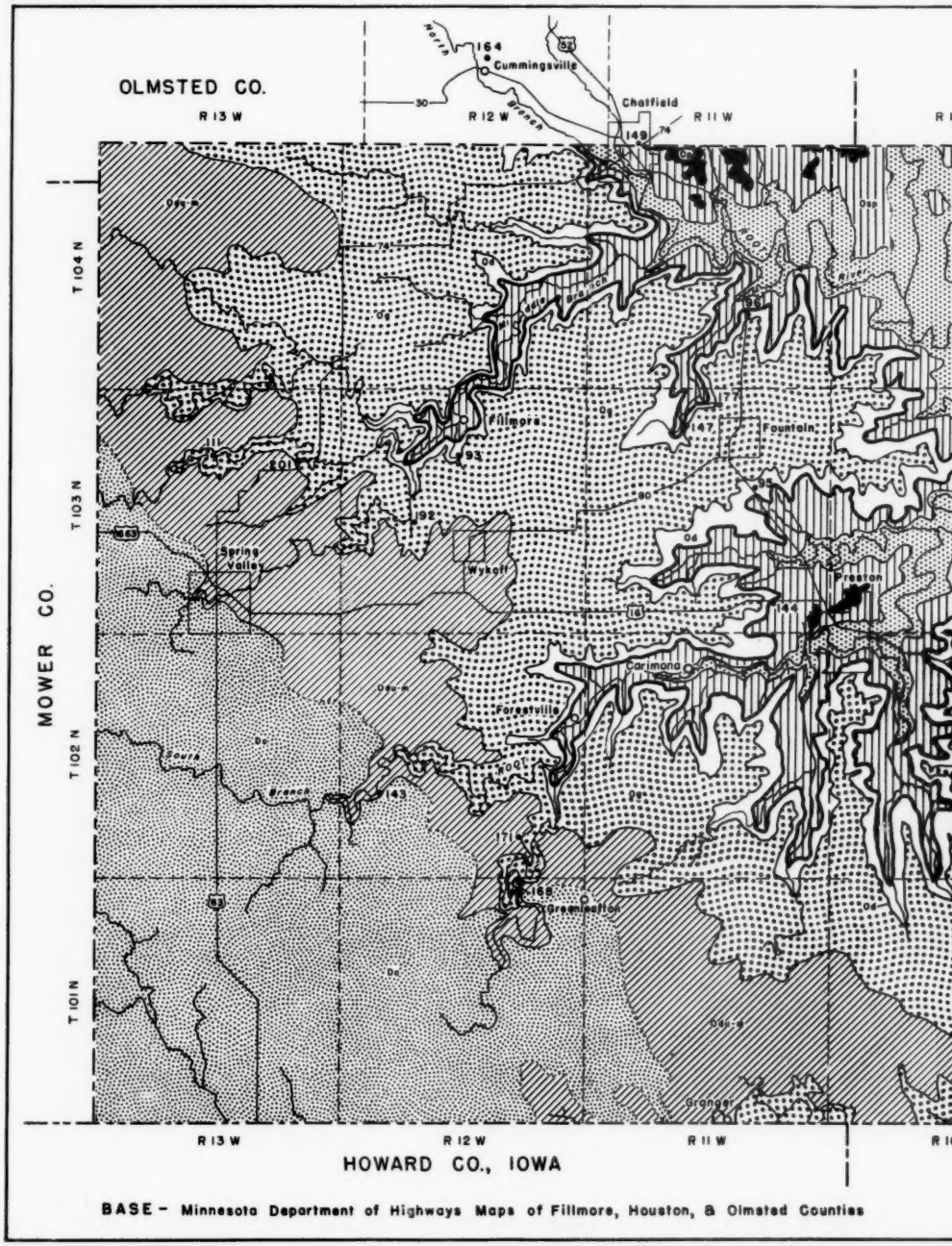
Dry hole (oil)





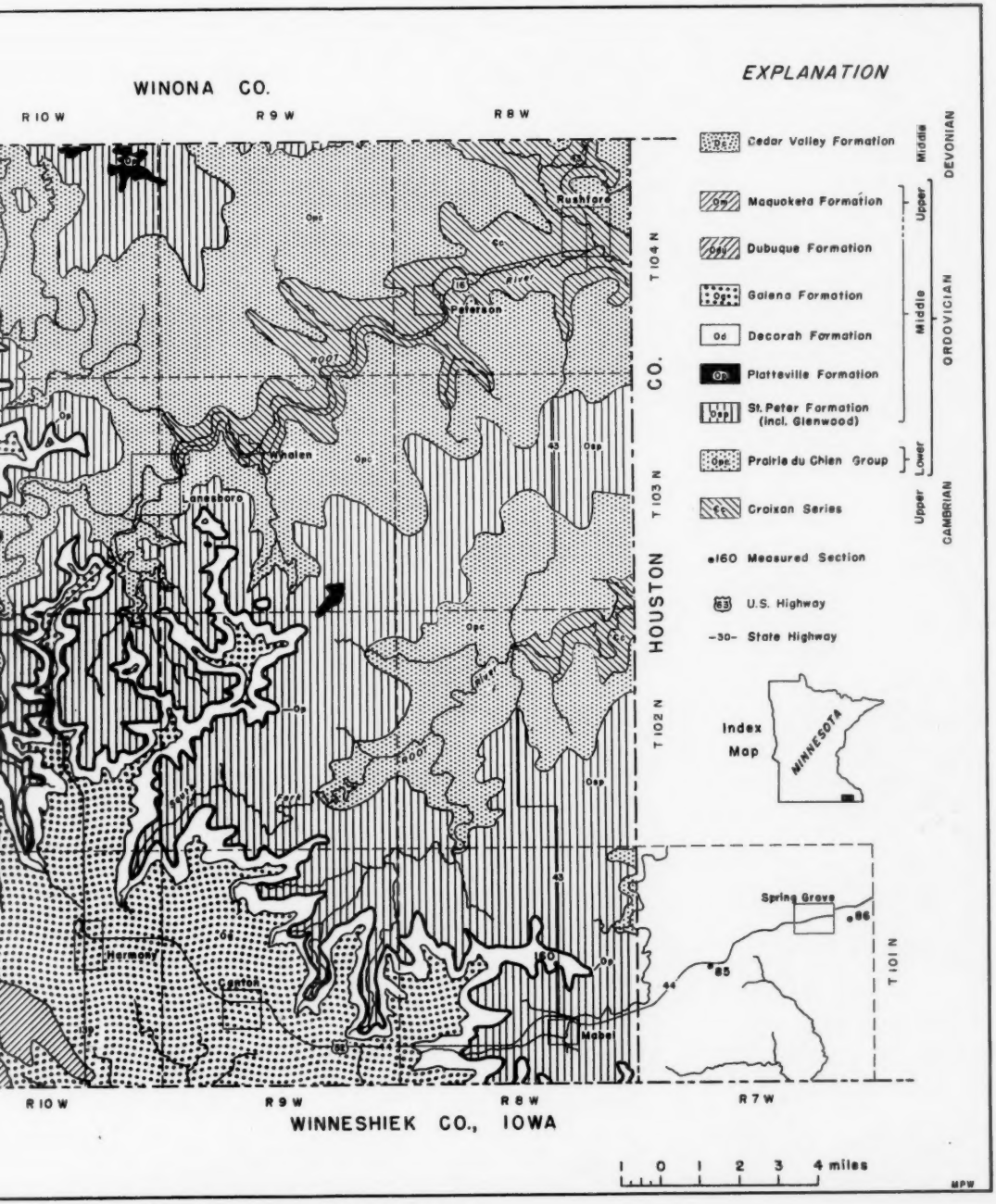


UADRANGLES, ARIZONA

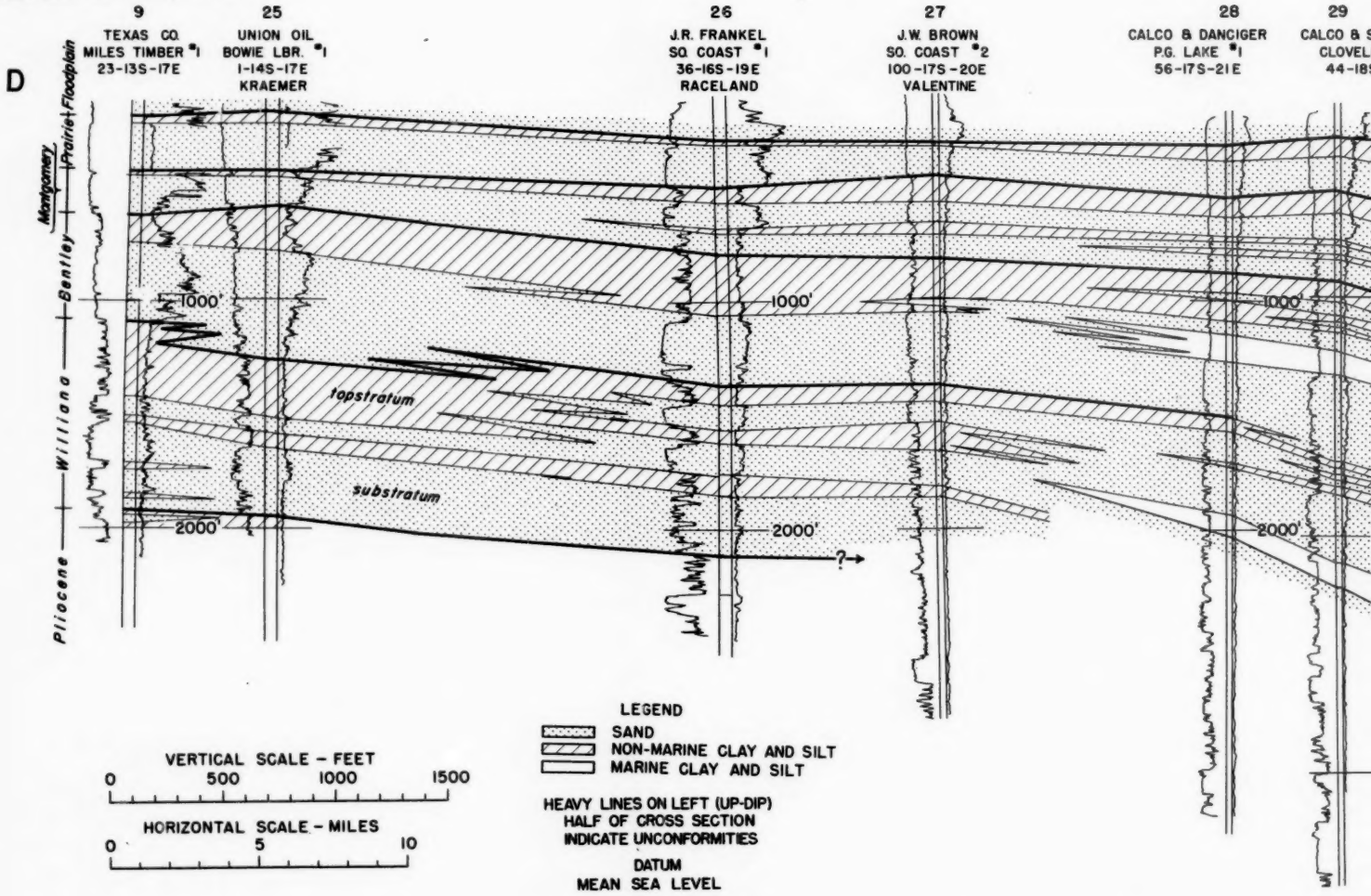


BASE – Minnesota Department of Highways Maps of Fillmore, Houston, & Olmsted Counties

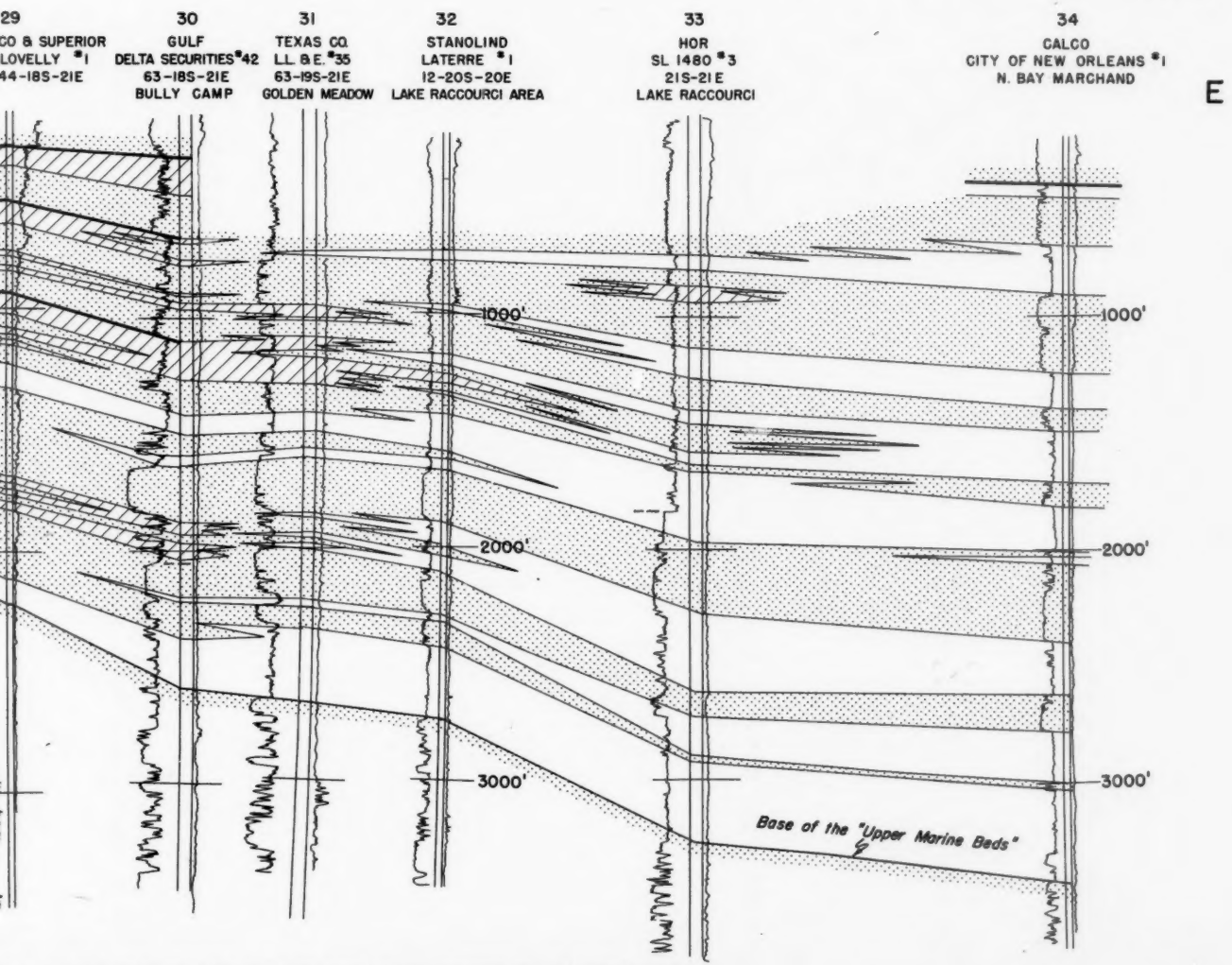
GEOLOGIC MAP OF FILLM



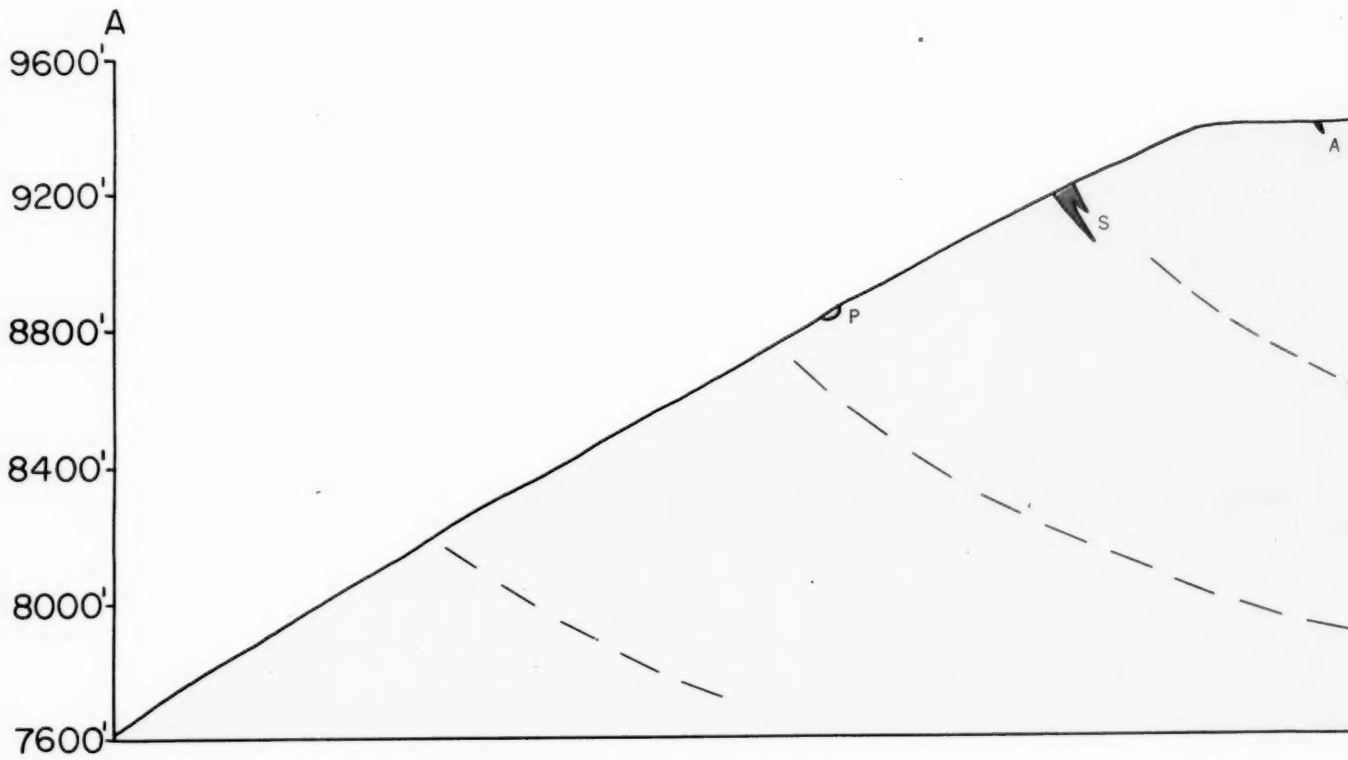
FILLMORE COUNTY, MINNESOTA

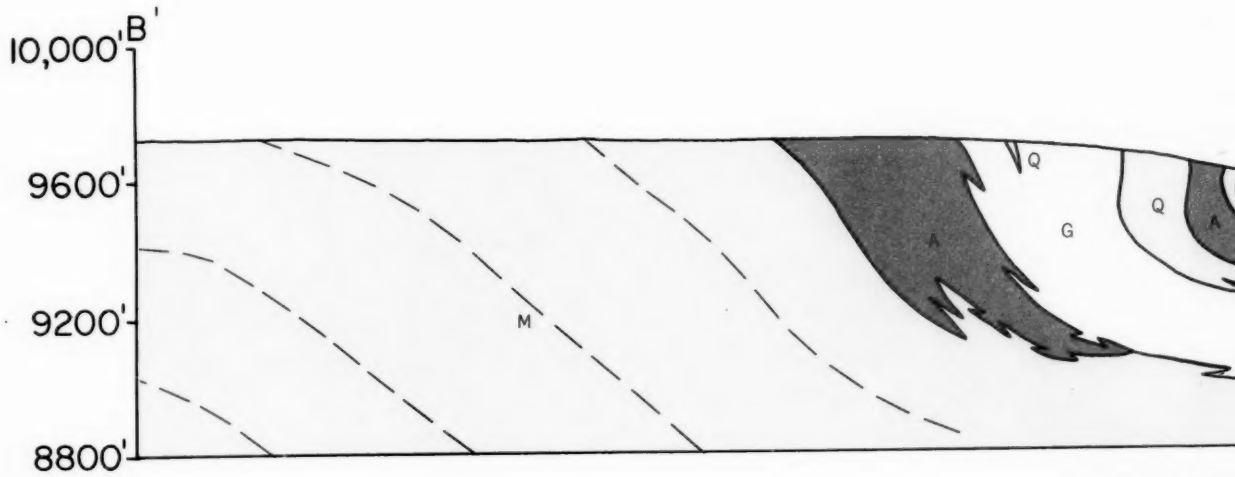


CROSS SECTION D-E WELL 36 MILES WEST OF NEW ORLE



LEANS TO BAY MARCHAND FIELD, LOUISANA





Viewed fro

LEGEND

CRETACEOUS

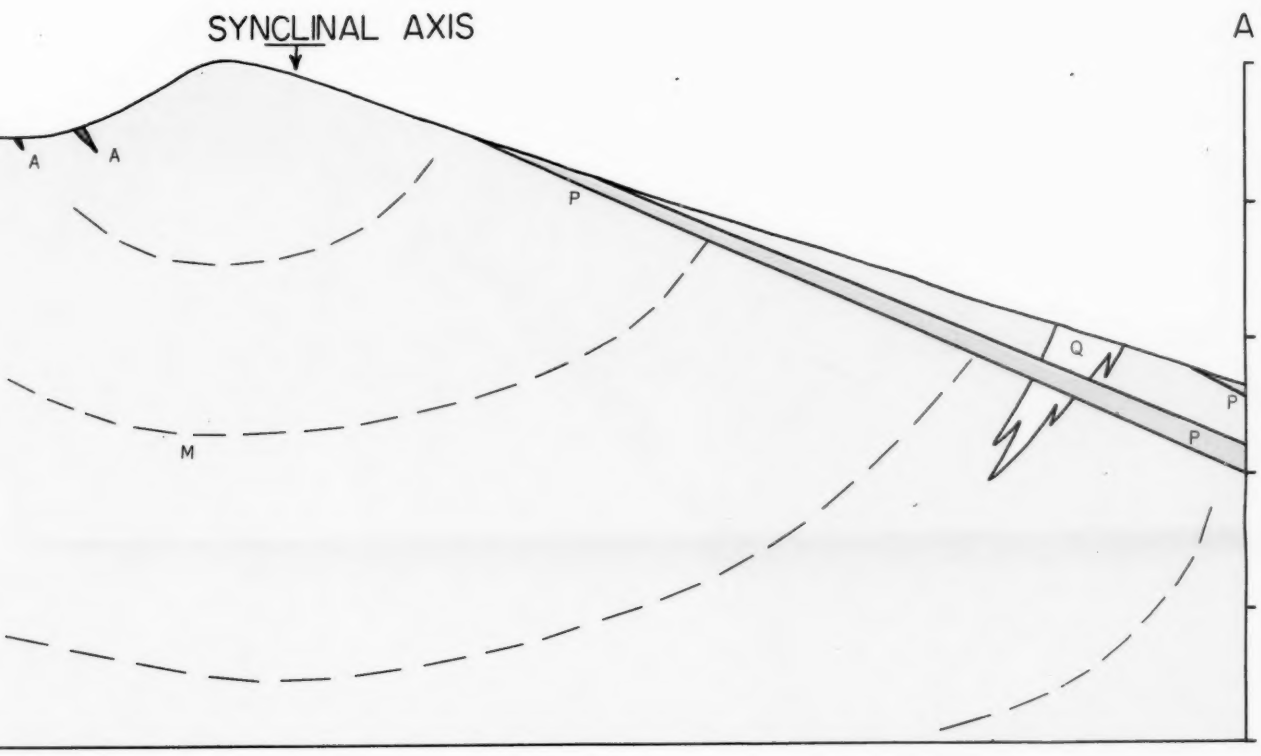
P — FELSIC PORPHYRY

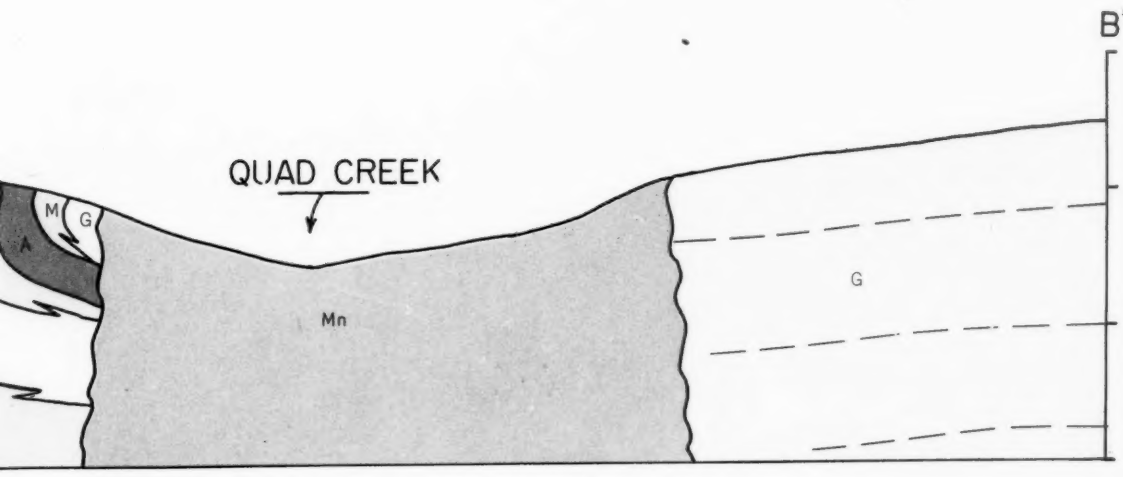
PRECAMBRIAN

G — LEUCOGRANITIC AND TONALITIC GRANITIC GNEISS
M — BANDED BIOTITE MIGMATITE
B — BANDED BIOTITE-HORNBLENDE MIGMATITE
Bm — MICROCLINE-BIOTITE MIGMATITE
Ag — AGMATITE
A — PARA- AND ORTHO-AMPHIBOLITE
S — BIOTITE SCHIST AND GNEISS
Q — QUARTZITE
An — ANTHOPHYLLITE ROCK
Mg — METAGABBRO
Mn — METANORITE
D — MAFIC DIKES

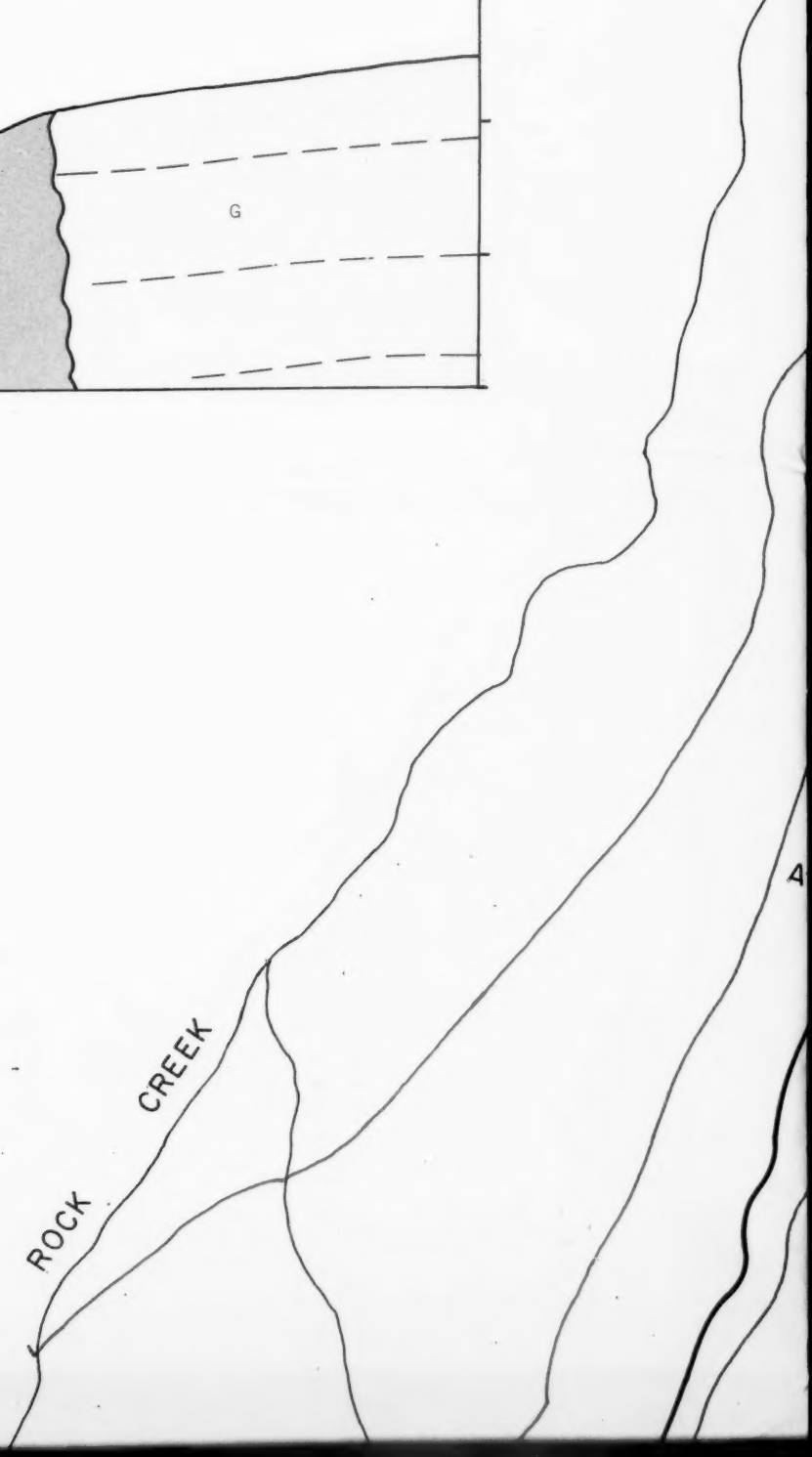
SYMBOLS

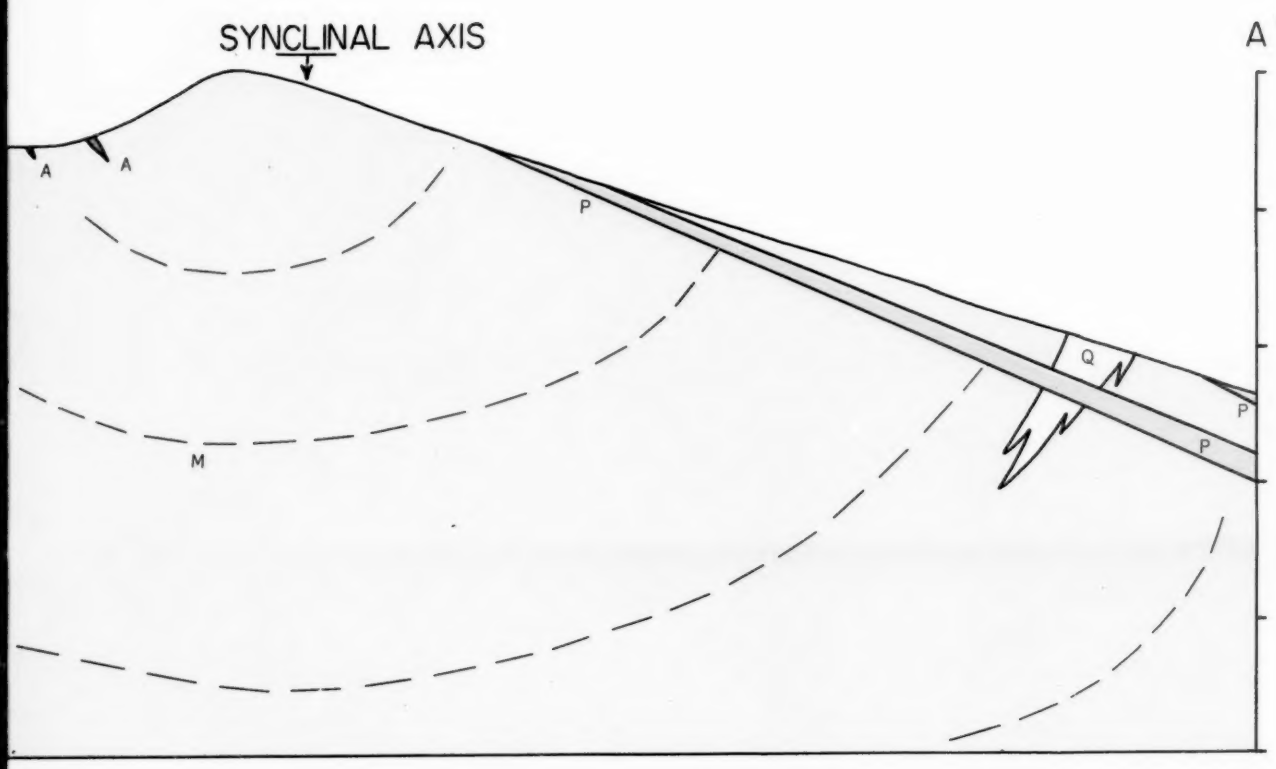
STRIKE AND DIP OF FOLIATION AND BANDING

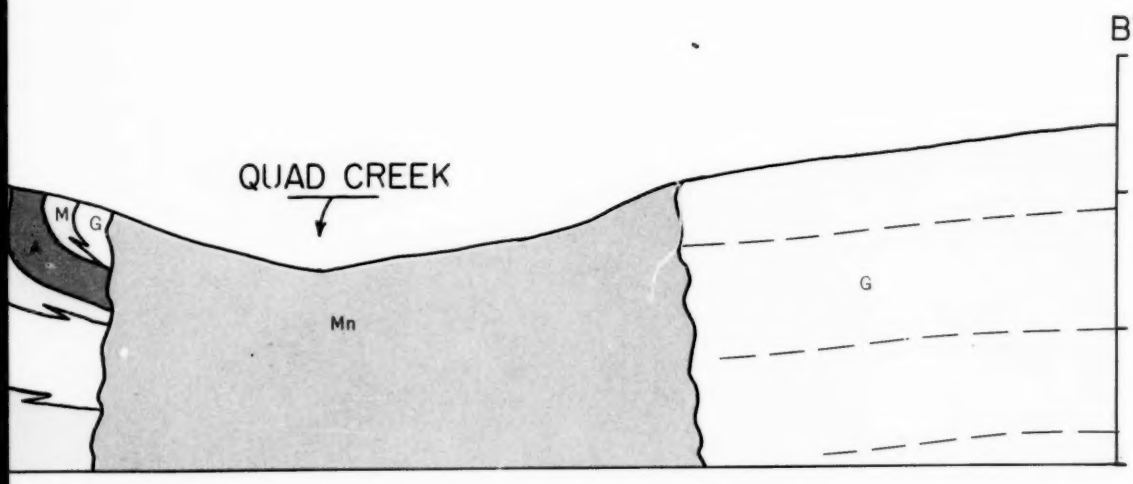




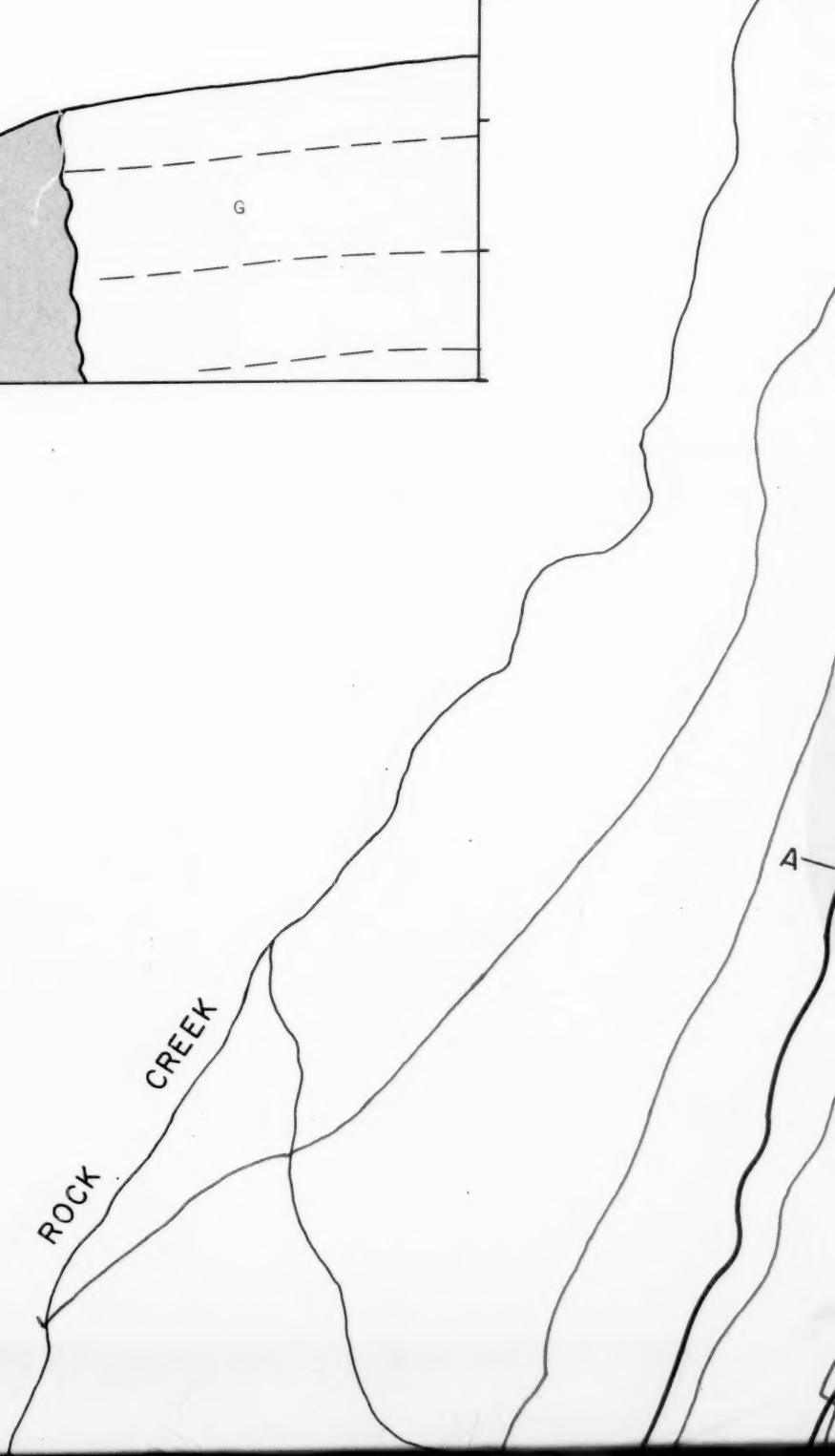
d from the west







d from the west



109°25′

US 12

MAE WEST

●259-34

METAGABBRO

Mg

●176-54

195-53

109°25'

US 12

MAE WEST

©259-54

METAGABBRO

Mg

©176-54

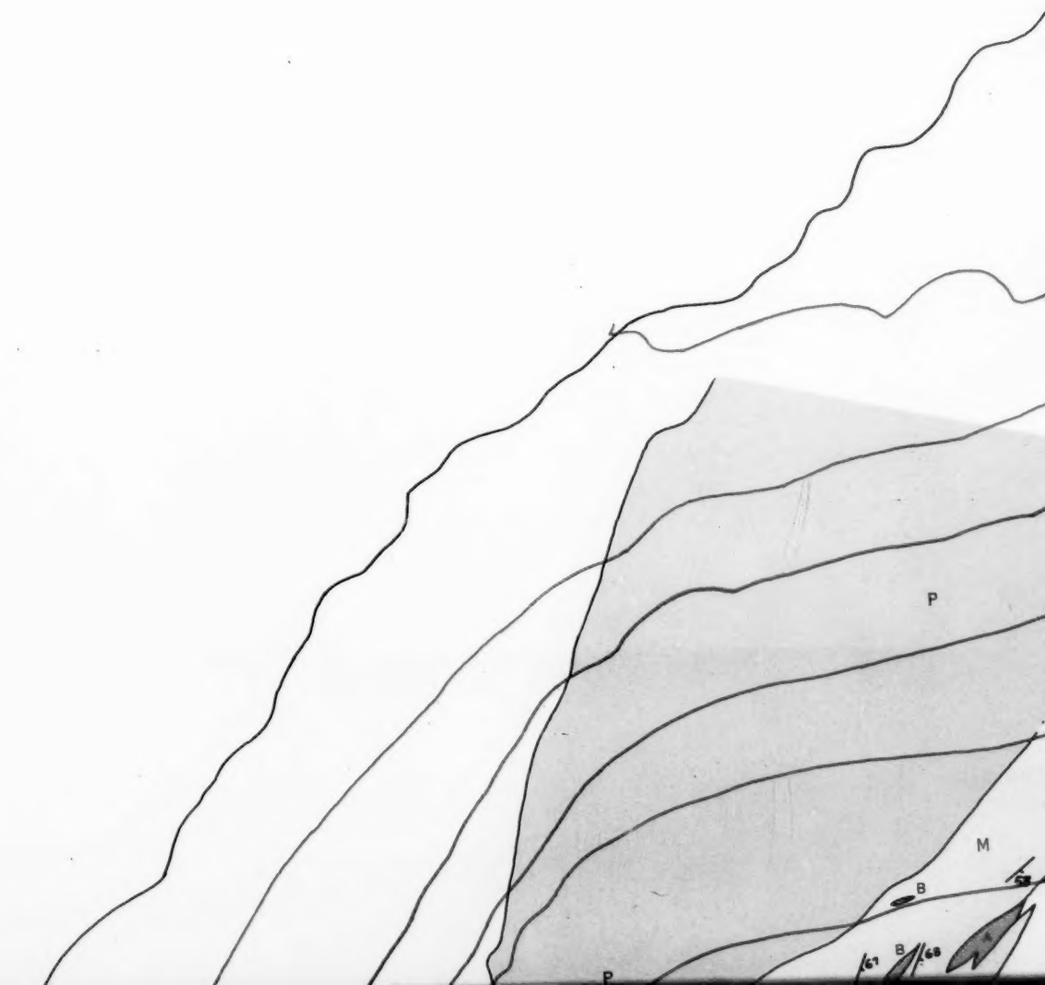
195-53

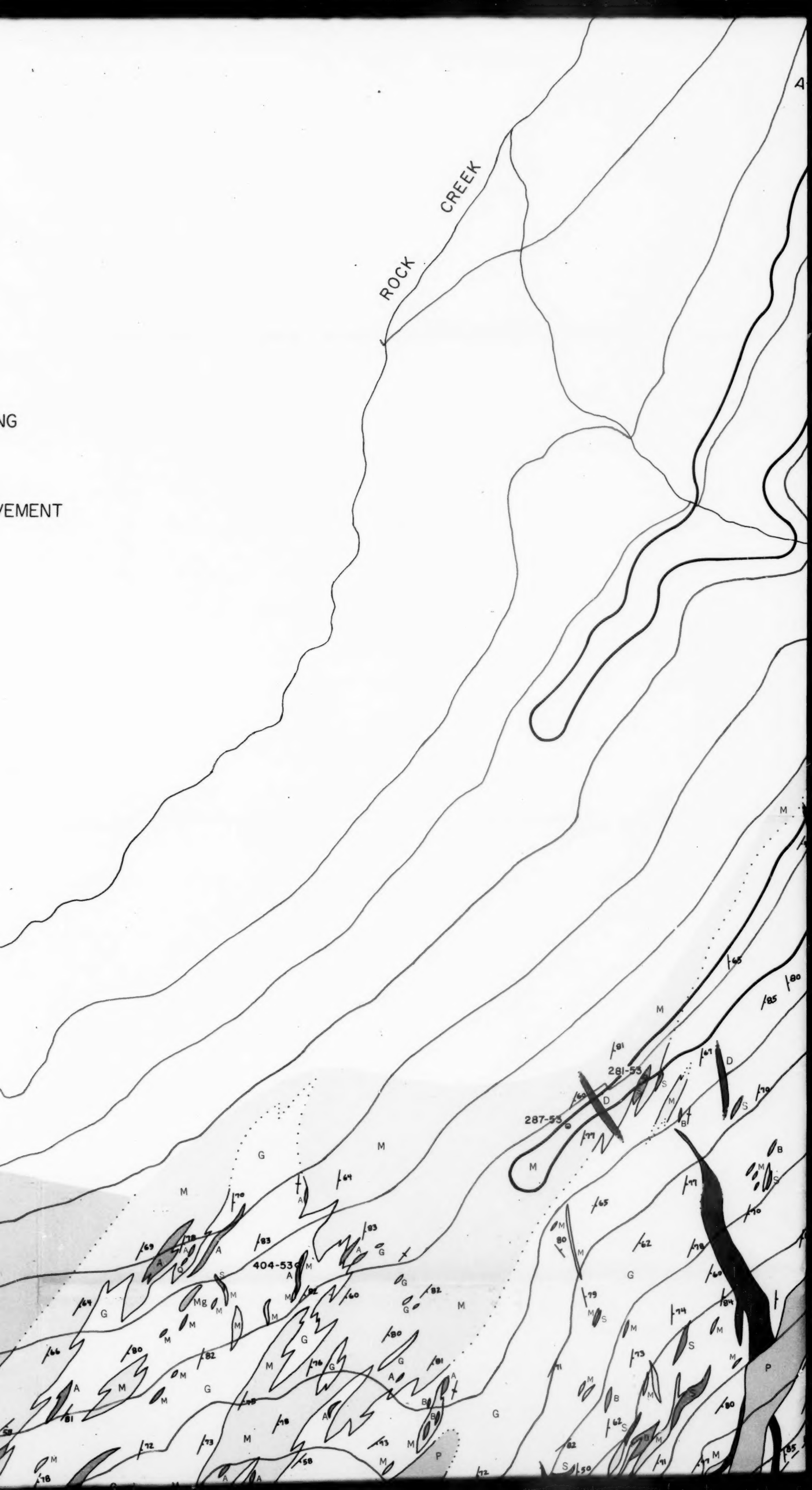
N
45°2'30"
MAE WEST
LOOKOUT
125-53

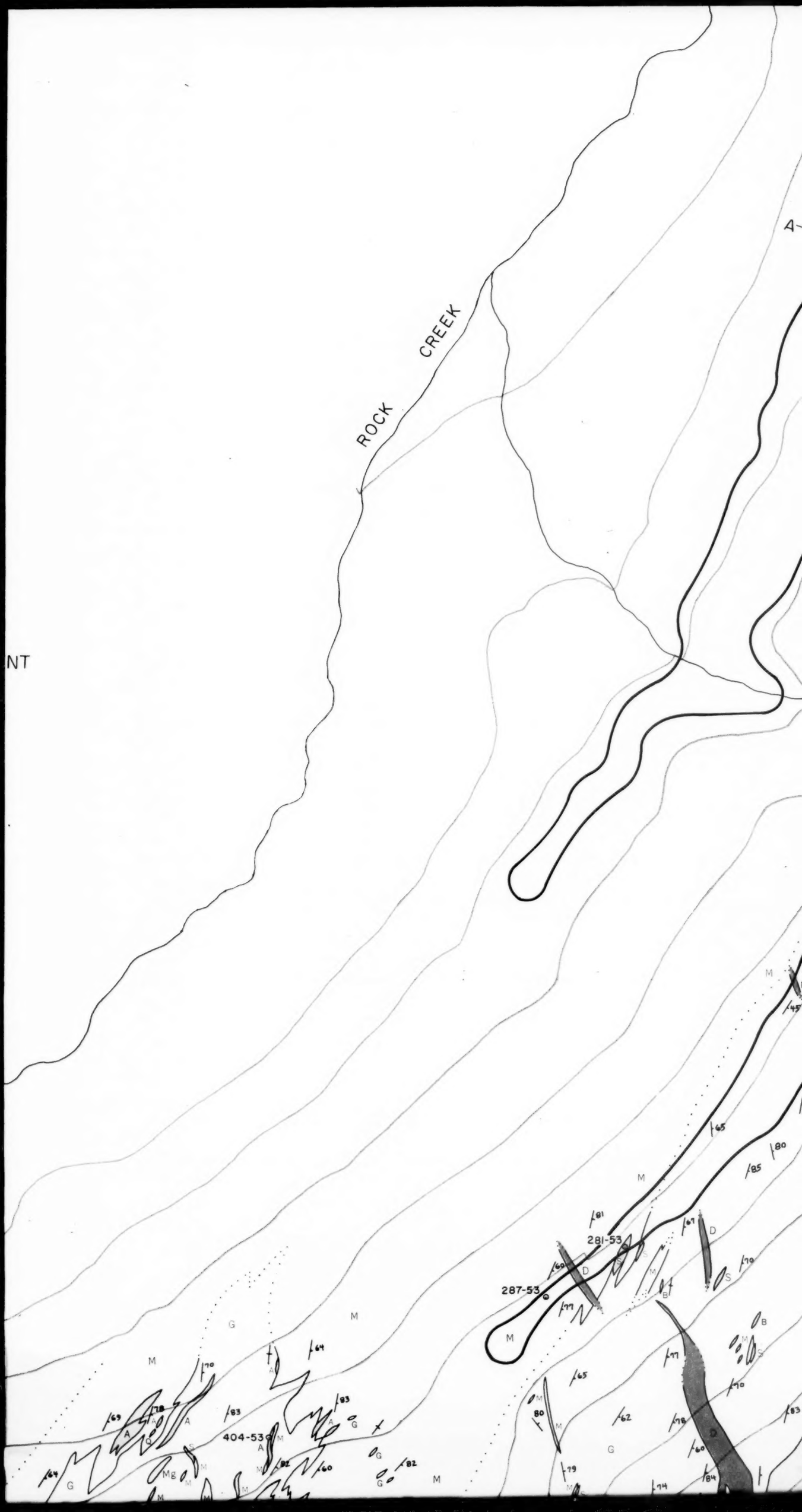
G LEUCOGRANITIC AND TONALITIC GRANITIC GNEISS
M BANDED BIOTITE MIGMATITE
B BANDED BIOTITE-HORNBLENDE MIGMATITE
Bm MICROCLINE-BIOTITE MIGMATITE
Ag AGMATITE
A PARA- AND ORTHO-AMPHIBOLITE
S BIOTITE SCHIST AND GNEISS
Q QUARTZITE
An ANTHOPHYLLITE ROCK
Mg METAGABBRO
Mn METANORITE
D MAFIC DIKES

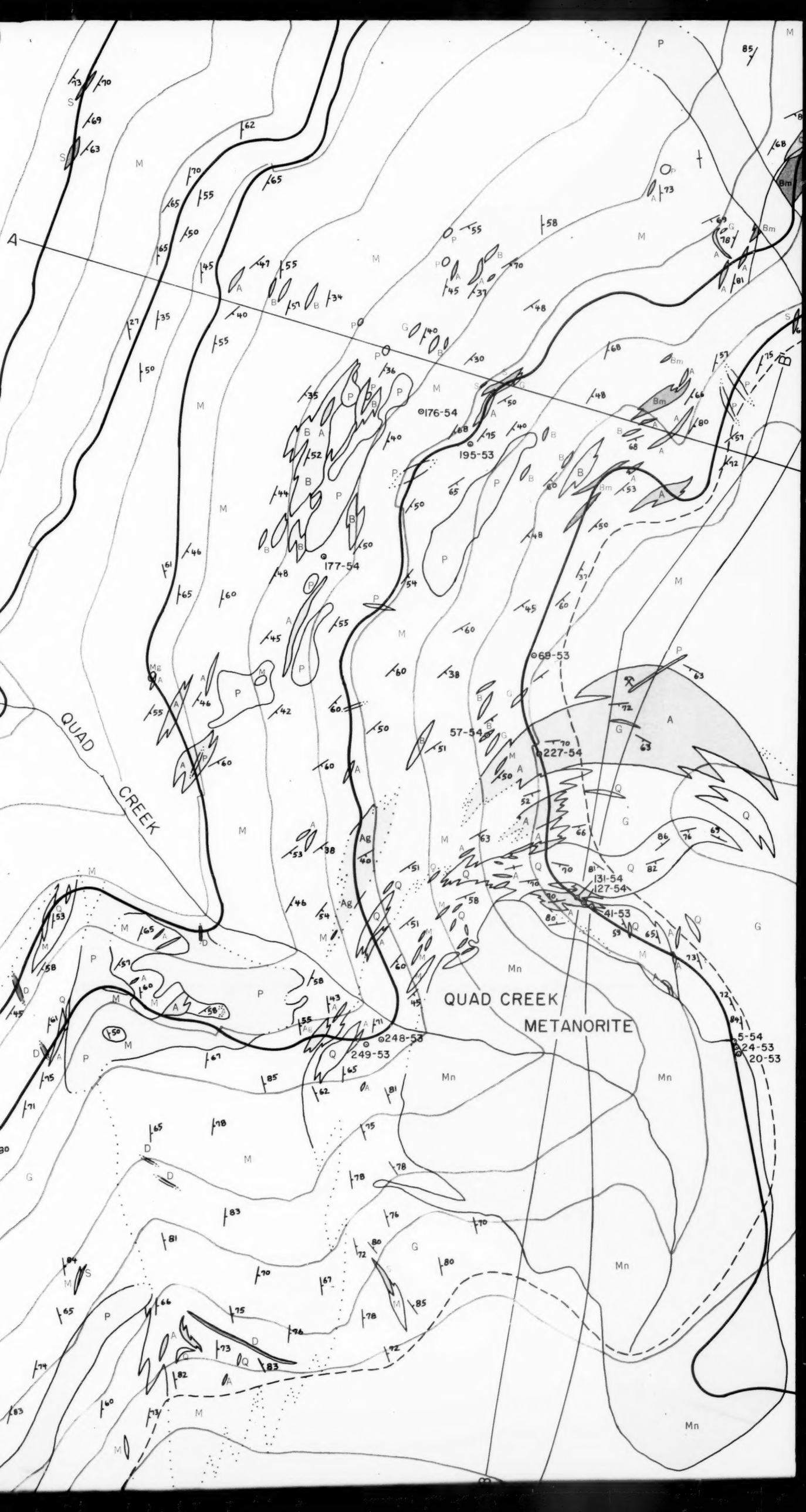
SYMBOLS

STRIKE AND DIP OF FOLIATION AND BANDING
STRIKE AND DIP OF VERTICAL FOLIATION AND BANDING
AXIS OF MINOR SYNCLINE
PLUNGE OF MAIN SYNCLINAL STRUCTURE
SEVERAL SMALL LENSES LESS THAN 20 FEET LONG
FAULT, ARROW INDICATES RELATIVE HORIZONTAL MOVEM
OBSERVED OR INTERPETED CONTACT
CONCEALED CONTACT
LOOKOUT
EDGE OF PLATEAU
MINE
LOCATION OF CHEMICALLY ANALYZED SPECIMENS
200' CONTOUR INTERVAL




ROCK CREEK
NG
VEMENT
281-53
287-53
404-53


ROCK CREEK
NT
281-53
287-53
404-53


A
B
QUAD CREEK
QUAD CREEK METANORITE
176-54
195-53
177-54
68-53
57-54
227-54
131-54
127-54
41-53
248-53
249-53
5-54
24-53
20-53
M
P
Mn
Ag
Bm
G
Q

QUAD CREEK

QUAD CREEK METANORITE

176-54
195-53
177-54
69-53
57-54
227-54
131-54
127-54
41-53
248-53
249-53
5-54
24-53
20-53

WYOMING

A

A'

14-55

125-53

45°2'30"

8000

9000

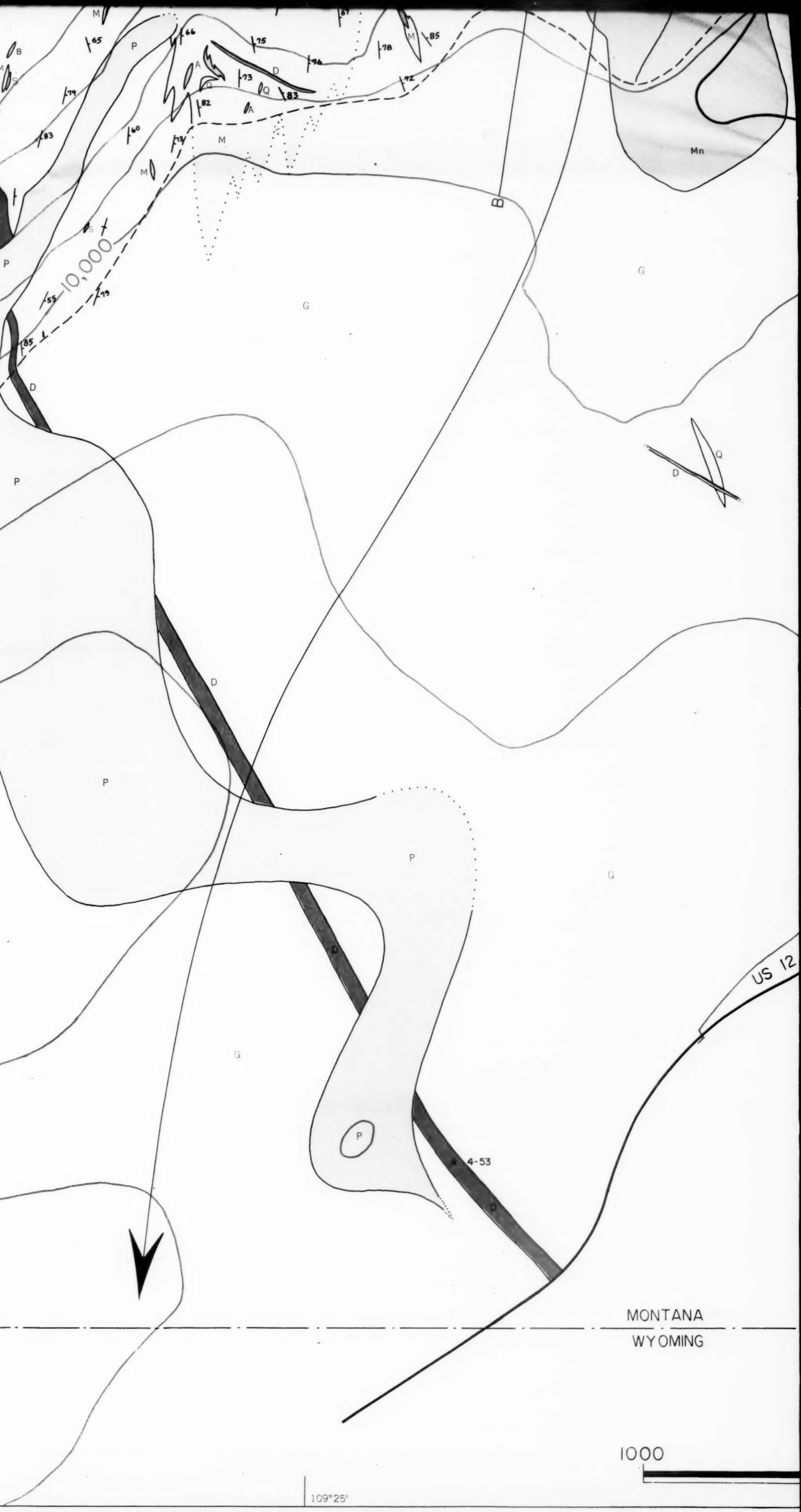
CHAIN

CREEK

©329-53

MAP AND CROSS SECTION OF T

MAP AND CROSS SECTION OF



OF THE QUAD CREEK AREA, MONTANA

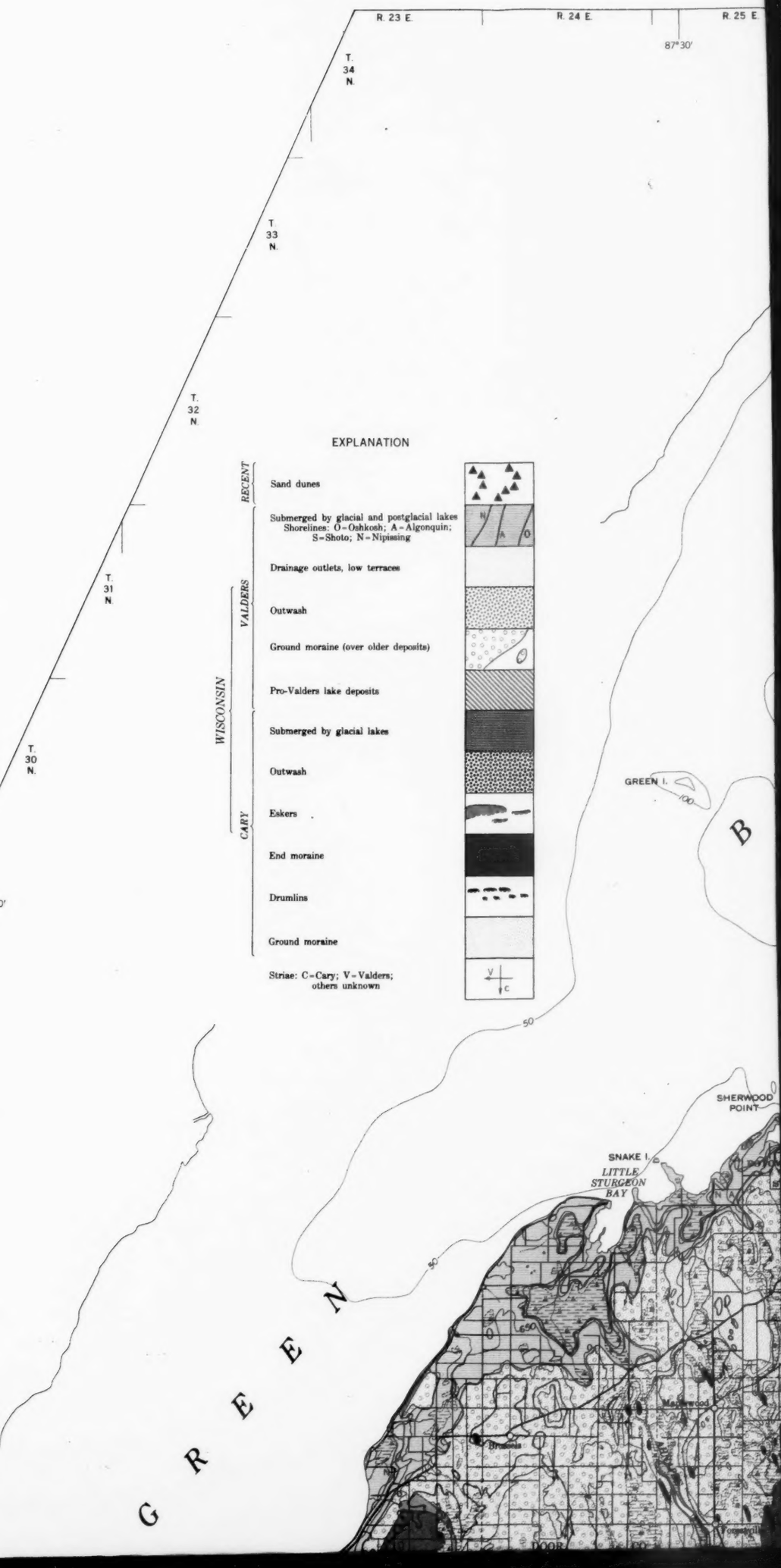
THE QUAD CREEK AREA, MONTANA

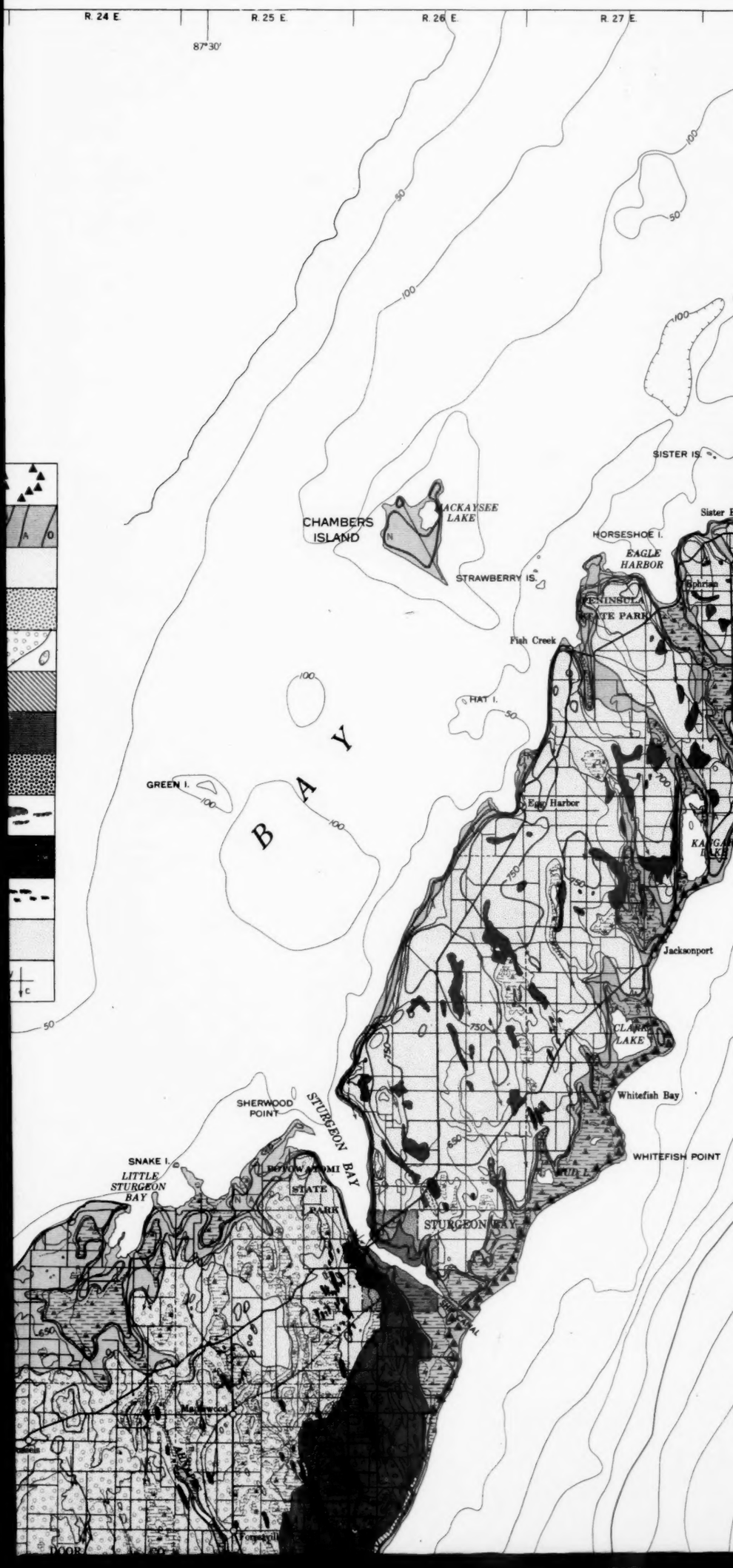
WYOMING CREEK

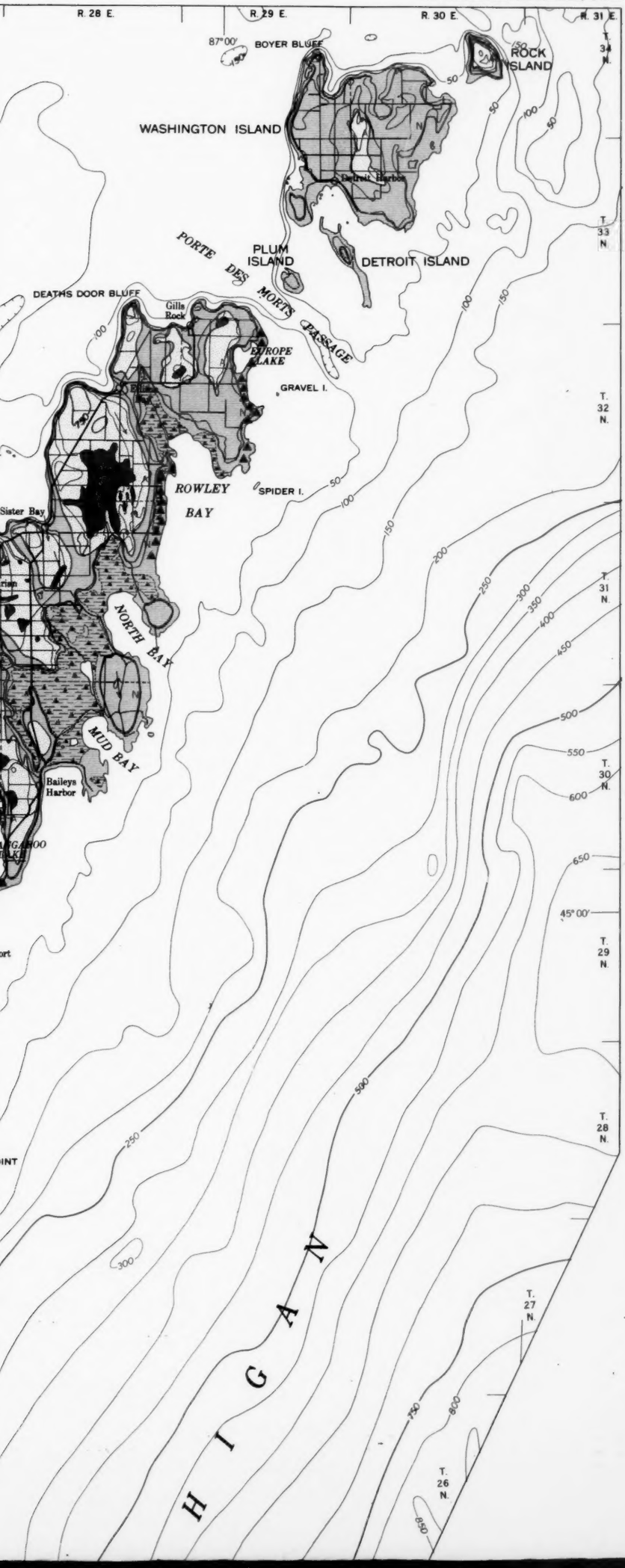
SCALE

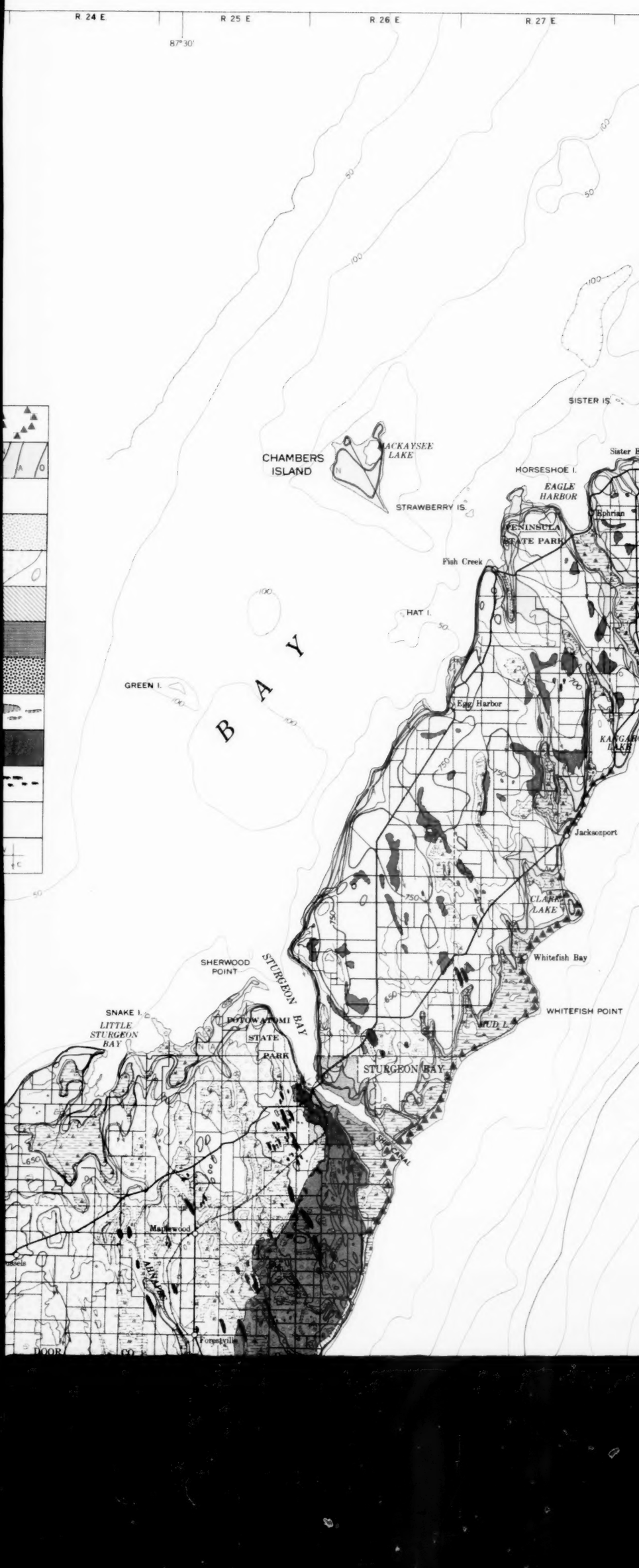
0 1000 2000 3000 FEET

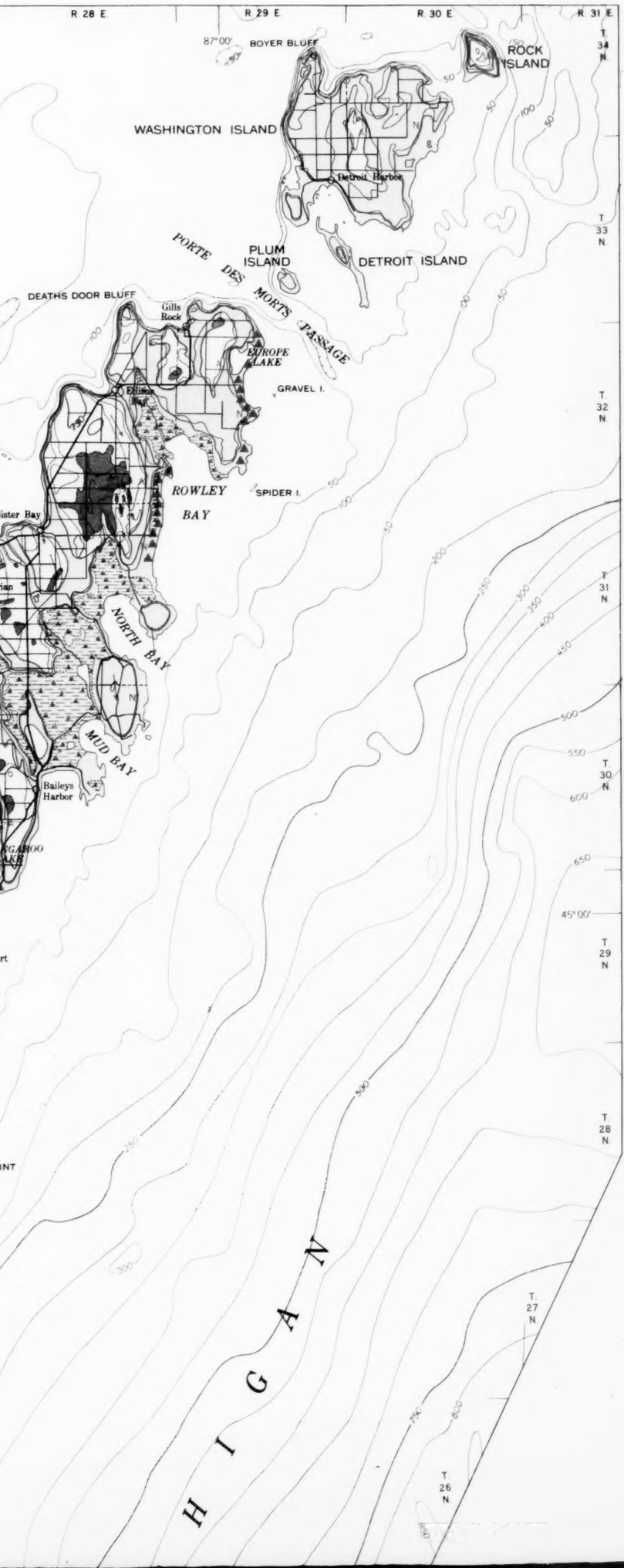
45°00'
T. 88°00'
29
N.
T.
28
N.
T.
27
N.
T.
26
N.

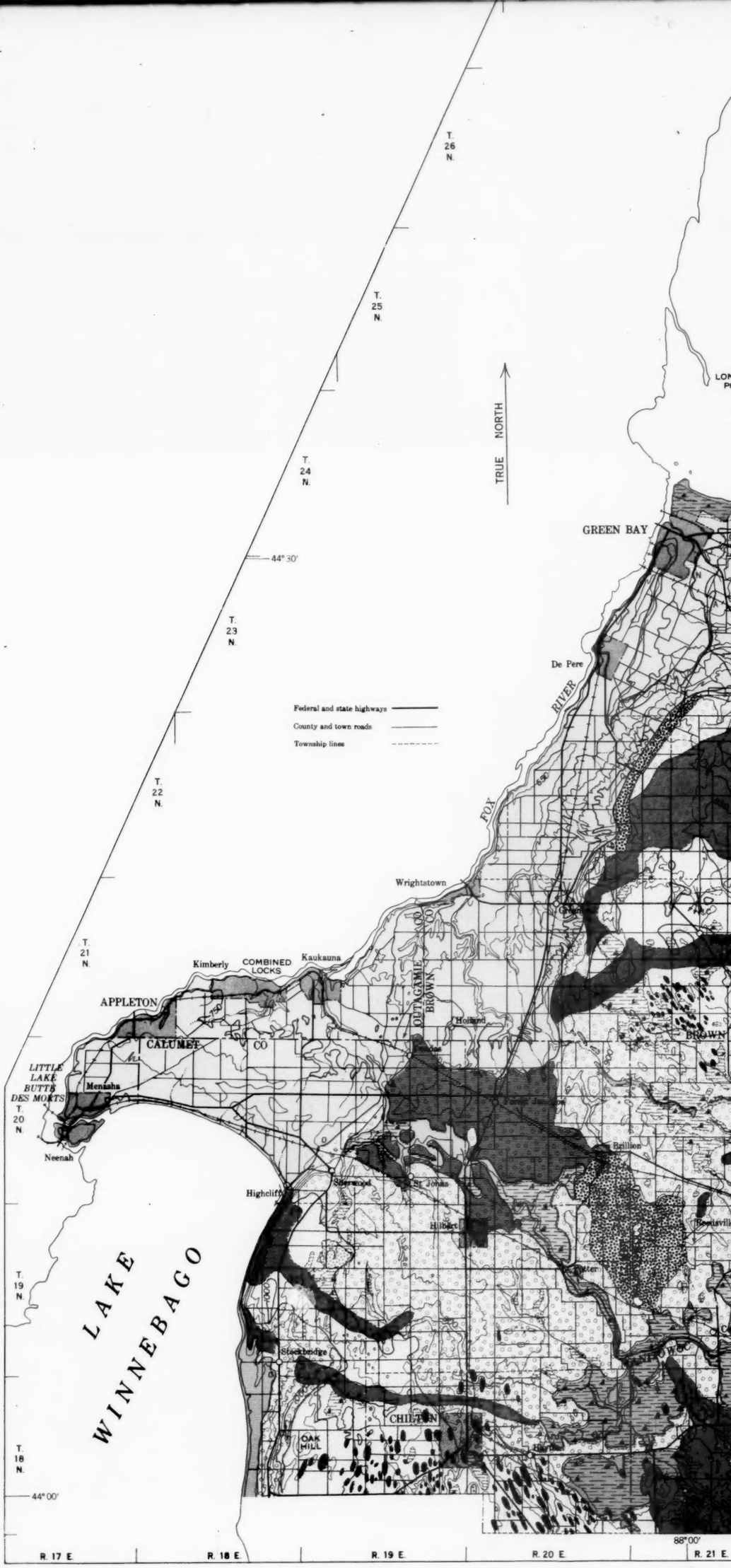

R. 23 E.
R. 24 E.
R. 25 E.
87°30'
T. 34 N.
T. 33 N.
T. 32 N.
T. 31 N.
T. 30 N.
EXPLANATION
WISCONSIN
RECENT
VALDERS
CARY
Sand dunes
Submerged by glacial and postglacial lakes Shorelines: O = Oshkosh; A = Algonquin; S = Shoto; N = Nipissing
Drainage outlets, low terraces
Outwash
Ground moraine (over older deposits)
Pro-Valders lake deposits
Submerged by glacial lakes
Outwash
Eskers
End moraine
Drumlins
Ground moraine
Striae: C = Cary; V = Valders; others unknown
GREEN I.
100
50
B
SHERWOOD POINT
SNAKE I.
LITTLE STURGEON BAY
650
Maplewood
Brussels
DOOR
GREEN


R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
87°30'
CHAMBERS ISLAND
JACKAYSEE LAKE
STRAWBERRY IS.
SISTER IS.
HORSESHOE I.
EAGLE HARBOR
PENINSULA STATE PARK
Fish Creek
HAT I.
GREEN I.
B A Y
Egg Harbor
Jacksonport
CLARK LAKE
Whitefish Bay
WHITEFISH POINT
SHERWOOD POINT
STURGEON BAY
SNAKE I.
LITTLE STURGEON BAY
POTAWATOMI STATE PARK
STURGEON BAY
Maplewood
Forestville
DOOR
100
50
750
650


R. 28 E.
R. 29 E.
R. 30 E.
R. 31 E.
87°00'
BOYER BLUFF
ROCK ISLAND
WASHINGTON ISLAND
Detroit Harbor
PLUM ISLAND
DETROIT ISLAND
PORTE DES MORTS PASSAGE
DEATHS DOOR BLUFF
Gills Rock
EUROPE LAKE
GRAVEL I.
ROWLEY BAY
SPIDER I.
Sister Bay
NORTH BAY
MUD BAY
Baileys Harbor
45°00'
T. 34 N.
T. 33 N.
T. 32 N.
T. 31 N.
T. 30 N.
T. 29 N.
T. 28 N.
T. 27 N.
T. 26 N.
MICHIGAN


R 24 E
R 25 E
R 26 E
R 27 E
87°30'
CHAMBERS ISLAND
MACKAYSEE LAKE
STRAWBERRY IS.
SISTER IS.
HORSESHOE I.
EAGLE HARBOR
Ephriam
PENINSULA STATE PARK
Fish Creek
HAT I.
GREEN I.
B A Y
Egg Harbor
Jacksonport
CLARK LAKE
Whitefish Bay
WHITEFISH POINT
SHERWOOD POINT
STURGEON BAY
SNAKE I.
LITTLE STURGEON BAY
POTOWATOMI STATE PARK
STURGEON BAY
Maplewood
Forestville
DOOR CO.

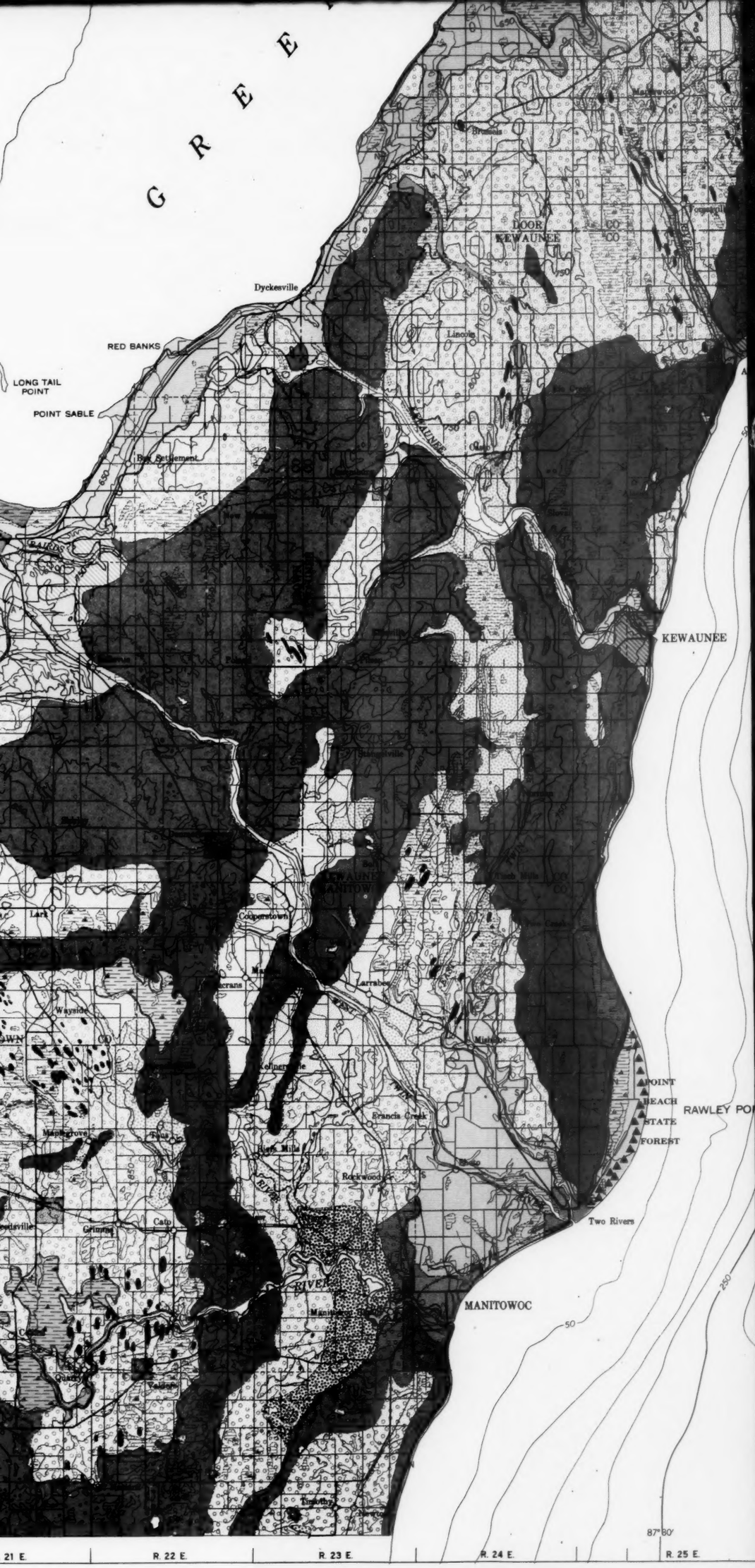

R 28 E.
R 29 E.
R 30 E.
R 31 E.
T 34 N.
T 33 N.
T 32 N.
T 31 N.
T 30 N.
T 29 N.
T 28 N.
T. 27 N.
T. 26 N.
87°00'
45°00'
BOYER BLUFF
ROCK ISLAND
WASHINGTON ISLAND
Detroit Harbor
PLUM ISLAND
DETROIT ISLAND
PORTE DES MORTS PASSAGE
DEATHS DOOR BLUFF
Gills Rock
EUROPE LAKE
GRAVEL I.
SPIDER I.
ROWLEY BAY
NORTH BAY
MUD BAY
Baileys Harbor
HIGAN



PLEISTOCENE GEOLOGY OF

By F. T

5 0

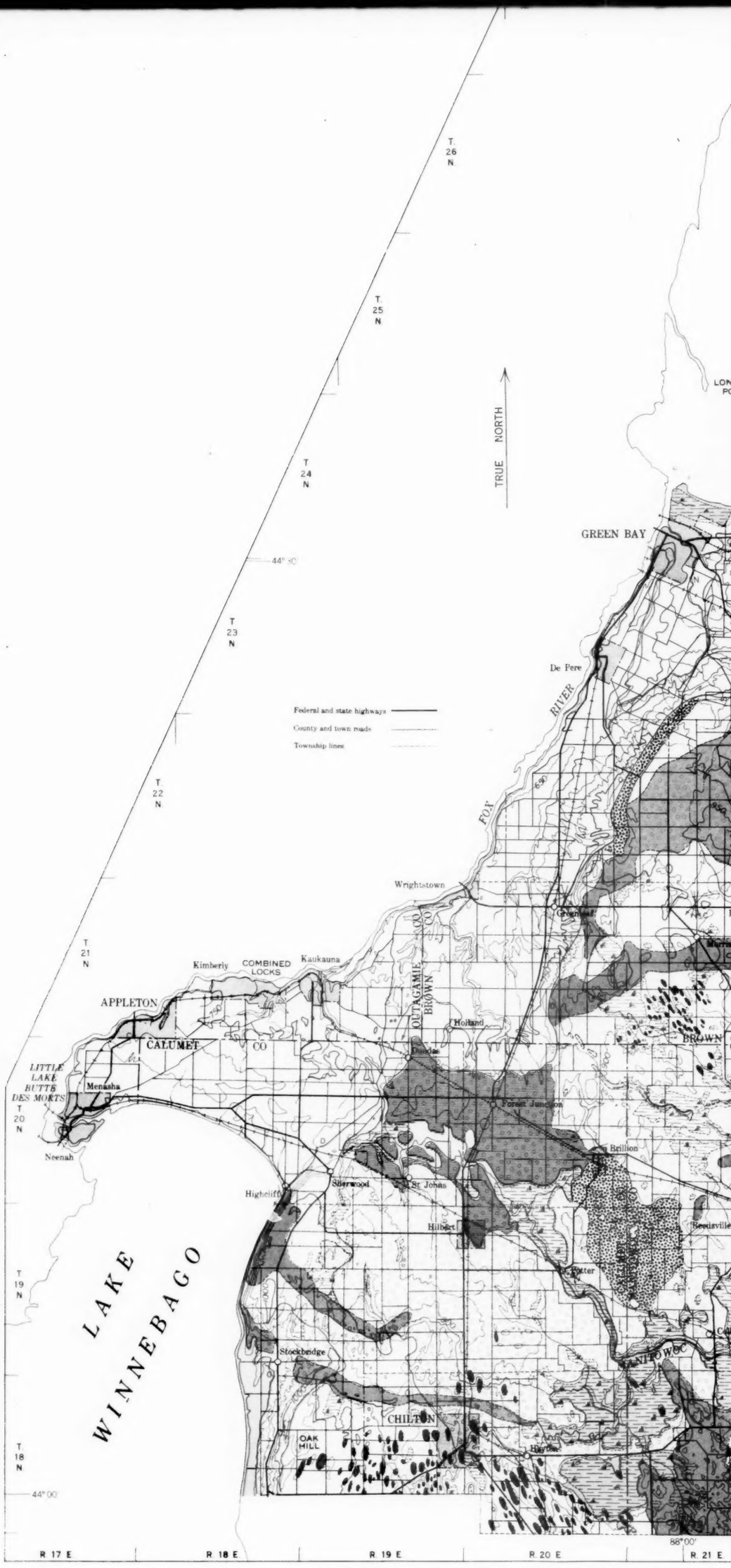


OF THE DOOR PENINSULA, WISCONSIN

y F. T. Thwaites and Kenneth Bertrand

5 10 15 Miles

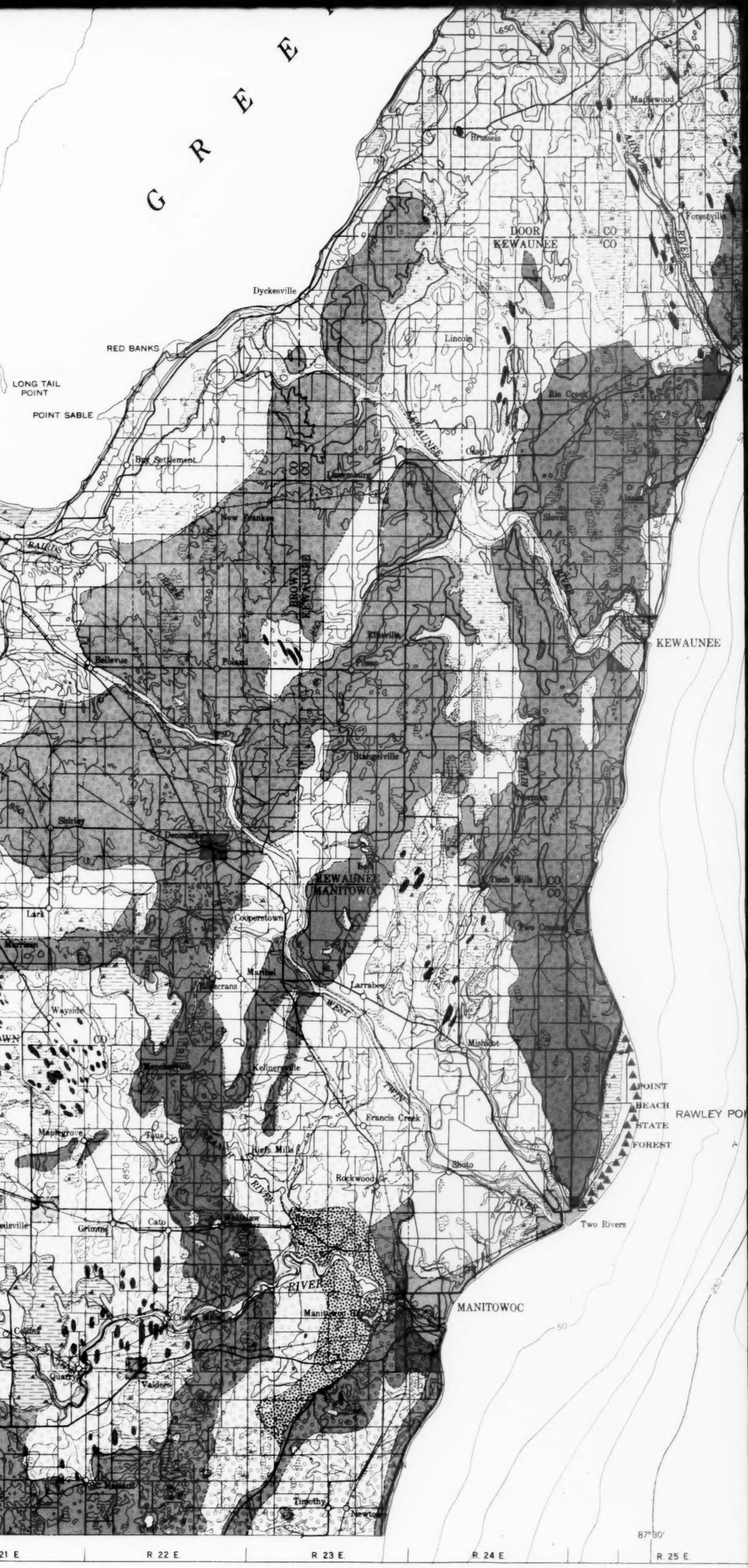
Contour interval 50 feet



PLEISTOCENE GEOLOGY OF

By F. T.

5 0



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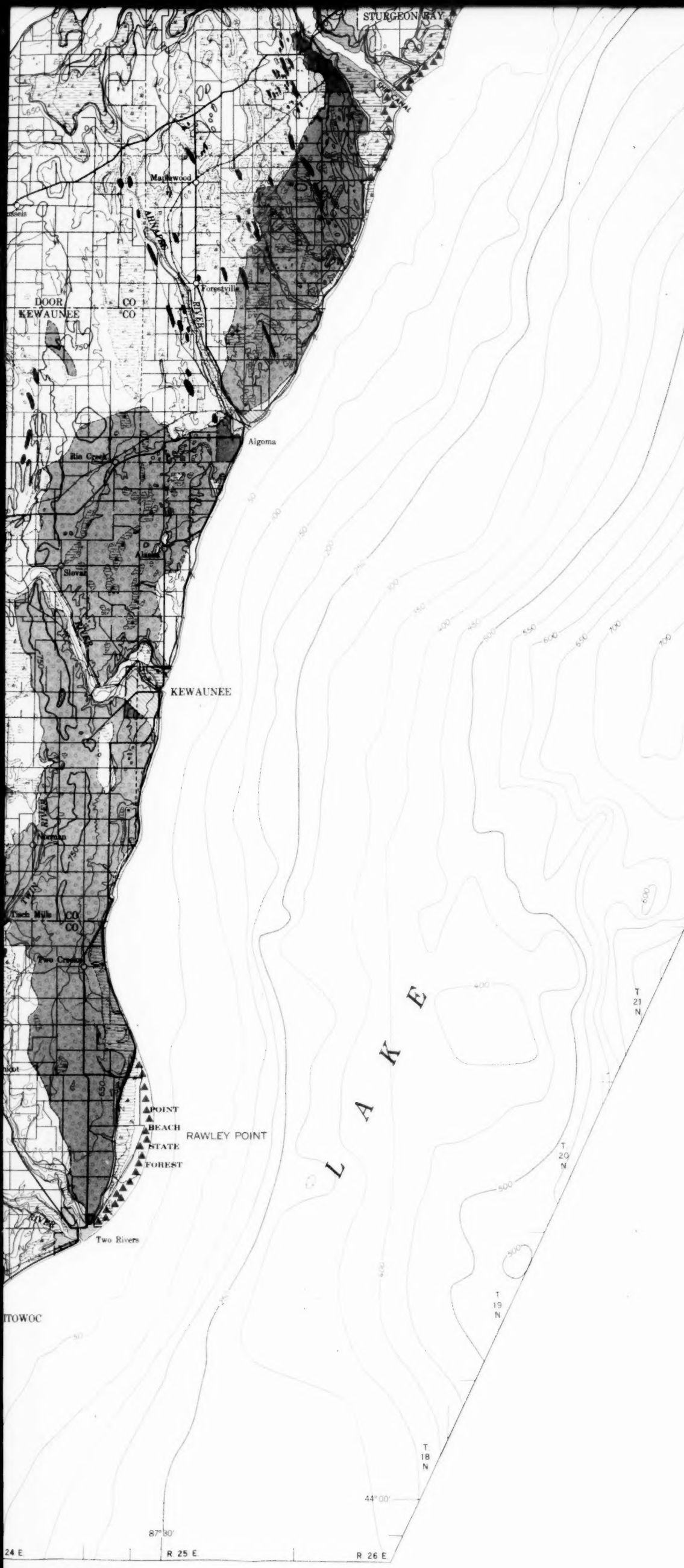
F. T. Thwaites and Kenneth Bertrand

5 10 15 Miles

Contour interval 50 feet



ITOWOC

SCONSIN

MICHIGAN
300
700
750
800
850
T. 27 N.
T. 26 N.
T. 25 N.
T. 24 N.
T. 23 N.
T. 22 N.
87°00'
44°30'

STURGEON BAY
Maplewood
Forestville
DOOR CO
KEWAUNEE CO
Algoma
KEWAUNEE
POINT BEACH STATE FOREST
RAWLEY POINT
Two Rivers
TOWOC
LAKE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
T. 21 N.
T. 20 N.
T. 19 N.
T. 18 N.
44° 00'
87° 30'
24 E.
R. 25 E.
R. 26 E.

SCONSIN

MICHIGAN
300
700
700
750
800
750
800
850
T.
27
N.
T.
26
N.
T.
25
N.
T.
24
N.
T.
23
N.
T.
22
N.
87°00'
44°30'